Progress Report
1990-1994

1. SUMMARY (Directors Overview)

I would like to begin my last Progress Report with a brief explanation as to why I have chosen to relinquish the Directorship of the APU several years ahead of retirement. There are two major reasons. At a personal level, I find that I am continuing to enjoy research just as much as ever; in the normal course of events I would retire in five years time, and following the very sensible MRC policy of discouraging ageing ex-Directors from continuing to haunt their old Units, would find myself looking for a new home as a pensioner. I much prefer the prospect of moving now, in order to initiate what I hope will be an extended programme of research in a new environment.

My second reason is that I believe that such a strategy would be better for the APU. For the past year we have been engaged in drafting the Unit's Progress Report, and it is likely to be a year from now before the Strategy Committee makes its decision about our work. That would leave four years to my retirement, and the normal course of events would be for us to produce another Report two years before my departure, which would then be used as a basis for deciding the future of the Unit and the selection of my successor. By the time he or she arrived, the Unit would have been in a state of greater or lesser disruption for a total of six years, with a restriction on appointing tenured staff operating over at least half of that period. While I am sure that the Council would be as flexible as possible, it is difficult to see how a prolonged period of uncertainty could be avoided, with its inevitably negative effect on the Unit's morale.

After discussions with the Office and my colleagues at the Unit, I therefore decided that I should retire, thereby allowing the current evaluation of the Unit's work to be combined with the decision as to the Unit's future, and I trust, the consequent search for a new Director.

The Remit of the APU

This Progress Report coincides not only with my own retirement from the Directorship after 20 years, but also with the Unit's 50th anniversary. I hope I can therefore be forgiven for taking this opportunity to look at the Unit's remit from a rather broader perspective than would normally be justified.

Throughout its first 50 years, the Unit has consistently operated at the interface between psychological theory and practical questions, basing general models of human cognition on specific empirical evidence, from both naturalistic and laboratory-based studies, and using this evidence in the attempt to solve applied problems.

The Unit's first Director, Kenneth Craik, was perhaps the first person to formulate clearly, and test empirically the idea of the computer as a model of complex human behaviour. He was tragically killed in a cycling accident one year after becoming Director, and was succeeded by Sir Frederick Bartlett who was also Professor of Psychology. Bartlett had a great talent for combining careful experimentation with the development of theory that was applicable to naturalistic as well as experimental data. As such he was a precursor of the subsequent so-called cognitive revolution of the 1960s, and his reputation has continued to be high both in Europe and North America. When he retired he was succeeded by Norman Mackworth, probably the least theoretically-oriented of the Unit's directors, but whose influence on the Unit continues to be strong, through the non-hierarchical management style he favoured, and not least because of his purchase of No. 15 Chaucer Road, the Unit's home since 1951.

When Mackworth later emigrated to Canada, he was succeeded in 1958 by Donald Broadbent, who shortly afterwards published Perception and Communication, a book that provided the first coherent theoretical account of cognition in terms of the information-processing metaphor previously developed by Craik. It was the forerunner of the revolution whereby cognitive psychology gradually became the dominant theoretical paradigm within psychology. While not supplanting other approaches, cognitive psychology has provided an information processing theoretical framework that allows integration across a wide range of areas, coupled with the potential for developing precise models in more closely specified areas. Broadbent's own work over the succeeding years illustrated this, as does the following Progress Report which represents a blend of approaches reflecting influences as diverse as neurophysiology, animal learning theory, clinical psychology and computer science. During Broadbent's 16 years as Director, he developed and consolidated the Unit's position as an international centre for research in pure and applied cognitive psychology.

During my own period as Director I have tried to continue this tradition. This has involved maintaining core strength in the major areas of cognitive psychology, and at the same time seeking areas of application that are tractable and fundable. Most importantly, such areas should be capable of feeding back results that will challenge and enrich the underlying theory. Psychology has been fortunate over the life of the APU in that it has always been possible to find such areas of application, although it has been necessary to change direction periodically in order to take full advantage of new opportunities.

The Unit was founded in 1944 on the basis of research projects stimulated by the Second World War, and for many years its work continued to be closely related to such military problems as pilot fatigue and the effect of environmental stress. Defence-related research was later largely replaced by problems stimulated by other Government departments such as the Post Office and Ministry of Transport. With the increasing importance of computers, a larger part of our work began to be carried out in association with industry, though sadly we have usually found it easier to establish research links with US, rather than British-based companies. In the present economic climate, however, even North American companies are rarely able to fund anything other than short-term research.

Fortunately, it has in recent years been increasingly clear that health-related problems present an ideal opportunity for applying and enriching cognitive psychology. Our initial ventures were into neuropsychology, where the careful study of single cases with relatively pure cognitive deficits caused by brain injury proved to be extremely fruitful. The field has developed to a point at which our concepts are now able to deal with a much wider range of cases whose cognitive deficits are less specific, and this in turn is stimulating the development of the new and related field of cognitive neuropsychiatry, whereby cognitive psychology is applied to the analysis and understanding of psychiatric disease.

Some 10 years ago, we decided to try to extend the range of cognitive psychology to include studies of the interaction of cognition and emotion, and were able to attract Watts from a senior clinical post at Kings College London. He was later joined by Teasdale from Oxford, and Williams from Newcastle, and in collaboration with Mathews and Macleod from St George's they succeeded in developing an approach that applied the concepts and techniques of cognitive psychology to the study of emotion and its disorders. This is now part of a vigorous area of overlap between cognitive psychology and the problems of clinical practice.

Our most recent attempt to blend cognitive psychology and practical problems is reflected in the neuropsychological rehabilitation group. While the group has not yet reached full size, or indeed gained access to its clinically-based accommodation, I am delighted with the progress that it has made in demonstrating the viability of neuro-rehabilitation as a fruitful applied area of the application of cognitive psychology.

One crucial advantage of our development of neurorehabilitation as a research area is the extent to which it is benefiting from the rapid development of clinical neurosciences in Cambridge. I expect us to continue to benefit from our growing collaborative links, in particular taking advantage of planned expansion of neuroimaging in Cambridge, and of the establishment of the IRC in Brain Repair. At present, the work of the IRC is principally concerned with animal models, but once the feasibility of clinical trials develops, then I would anticipate close collaboration.

It is clear that many of my colleagues see considerable potential for collaboration between cognitive psychology and the neurosciences. I hope my successor will be as enthusiastic about that prospect as I am. At the same time, I trust that he or she will bear in mind that the Unit's success has come from its capacity to maintain considerable strength in the core areas of cognitive psychology, providing a solid scientific base that is capable of capitalising on whatever area of application is currently most productive, while allowing sufficient flexibility to seek other applications when the time is ripe.

Although the Unit's general remit has remained much the same, the form and content of its scientific contribution has evolved under each of its successive directors. Looking back over the period since 1974, I would like to think that research by APU staff has not only kept up with the best national and international work in both pure and applied cognition but also has continued to help shape the core agenda for our principal fields of operation.

In the mid seventies, the domains of coverage for theory and experimentation were largely those of traditional information processing psychology. Fractionation of component operation in simple pure and applied tasks was the dominant mode of scientific enquiry guided by locally constrained mathematical models, "box" models or verbally formulated theory. In the mid nineties, fractionation plays a key role but is now embedded in a much more interdisciplinary outlook. Our typical tasks now range from simple to complex; our theories tend to be more integrative; our empirical methods are of far greater relevance to charting performance in clinical as well as normal settings. A substantial proportion of our modelling effort is now routinely implemented, for example, mathematical models of auditory image creation, connectionist models of language or memory systems, or symbolic representations of mental models or of complex task performance. Not only the form of the theory has developed; its content now extends outwards to form interdisciplinary links with the basic cognitive sciences of linguistics, artificial intelligence and computer sciences through to clinical disciplines and neurosciences. In each of these areas it can be argued that researchers at APU have played their part - reference to core research summaries and teaching texts testifies to this. I hope that the tools, techniques and theories now in place will form a substantial and relevant foundation for future advance in all of these areas.

What follows in this introduction is my overview of the major advances during the last five years of work at the APU, and also of plans for future work, organised into six scientific programmes. Creating an environment for these advances has been a stimulating and thoroughly enjoyable challenge, made possible by the MRC Unit system. Long may it flourish!

Programme 1: Perception and Action

The purpose of this programme is to develop models of perception at a level between sensory physiology and cognition - models that enable us to make quantitative predictions about perception and behaviour in circumstances where they are predominantly governed by the external stimulus. The research falls into three broad areas, one concerned with audition, a second with vision, and a third with the control of movement. All three areas are well established at the Unit, and in the last five years we have been able to capitalise on theoretical advances to produce patents which have been developed commercially.

Roy Patterson's Auditory Image Model, described in our last Progress Report, has been substantially developed over the period, with much of the work being achieved through collaborations with European colleagues through an ESPRIT contract, and subsequently with North American and Japanese groups. Considerable software development has led to a user-friendly version of the model that was made generally available on Internet, resulting in transfer to 125 sites within the past eight months. The model has proved to be an effective "front end" for speech perception and performs somewhat better than the leading FFT preprocessor for both phoneme recognition and speaker identification, despite the fact that the full capacity of the model was not realised in these initial tests.

Theoretical exploration of the model has been primarily concerned with explaining the perception of sound quality or timbre. Traditionally, auditory models predict our perceptions from the power spectrum of the stimulus. Patterson's model differs in assuming asymmetry in the auditory filter system, which predicts that ramped tones, in which the sound pressure increases gradually and terminates suddenly, will give rise to a very different auditory image from damped tones which have the reverse temporal pattern, despite the fact that ramped and damped sounds have identical power spectra. As Patterson's model predicts, marked perceptual differences occur, whether the sound sequences are based on pure tones or noise.

One of the earliest practical products of Patterson's psychoacoustic research was a system for designing auditory warnings that are maximally audible without being startling, highly discriminable, and easy to learn. Warnings designed on these principles are currently used in North Sea helicopters and were used in RAF helicopters in the Gulf War. Subsequent work has developed warnings for civil aircraft and fixed-wing military planes, and the same principles have been applied to developing trackside warnings for British Rail workers and an international standard for warnings in hospital operating theatres and intensive care units.

Future work will continue the development of the auditory image model with a more user-friendly interface and a simulation of the physiological characteristics of the cochlea that should extend its application to the analysis of hearing disorders (in collaboration with colleagues in the Cambridge Psychology Department). In a collaboration with Armstrong Laboratories in the U.S.A. the model will be implemented on an analog VLSI chip as part of an international programme to develop a "silicon cochlea". Utilisation of the model as part of an automatic speech processor will continue in collaboration with Armstrong Laboratories and with ATR in Kyoto.

Future theoretical work will concentrate on two synthetic sounds which produce complex tone and noise perceptions that traditional auditory models fail to explain. The stimuli are matched pairs of damped and ramped sounds, and iterated rippled noise. The perceptions are interpreted in terms of the time-interval patterns the sounds produce in the auditory image. Finally, we will continue to provide expertise in the development of auditory warnings, as and when appropriate.

The psychoacoustics programme has recently been further strengthened by the appointment of Carlyon, who was 1994 recipient of the Acoustical Society of America's Bruce Lindsay Award. He will be studying the physical factors that allow a listener in a noisy room to pick out a single sound source from the complex and intermingled signals at the ear.

In the area of vision, Wilkins has extended his earlier work on photosensitive epilepsy to a wider population, resulting in a general theory of visual stress and discomfort. He has shown that certain frequencies of stripe or flicker are particularly likely to lead to visual distortions, reading problems and headaches in non-epileptic subjects, a response he attributes to the hyperexcitability of neurons in the visual cortex. The theory has relevance for lighting, text design and the development of visual display units.

Recent work has concentrated on the observation that ophthalmically-tinted spectacles can reduce symptoms in susceptible individuals. The optimal tint varies from one subject to another, and so Wilkins has developed an instrument (the Intuitive Colorimeter) that facilitates measurement of the appropriate tine. This has been validated, and is now commercially available. It is being used increasingly widely and it appears to be particularly helpful for certain children with reading difficulties. A simplified assessment procedure using transparent overlays has been devised for screening purposes, and will be further developed over the next few years.

Future plans involve collecting more evidence on the capacity of the model to deal with migraine headaches, and will investigate the therapeutic value of using ophthalmically-tinted lenses. Other applied issues include the study of photophobia in recently head injured patients.

At a more theoretical level, the processes underlying visual discomfort will be further explored using psychophysiological measures including pupil size, eye movements and cortical evoked responses. The optimal method of testing the hyperexcitability theory however, is through PET scanning or functional MRI, both of which should be available locally in the near future.

Wing and colleagues have continued to study the timing and control of movement. His widely used two-level model for repetitive movement has been elaborated into a multi-level, hierarchical model for rhythm. This has been shown to be applicable to situations in which the control of timing is explicit, but not to the timing of patterned responding in tasks such as typing and handwriting in which the rhythm emerges from the task, rather than being explicitly imposed. Yet a third variant on timing occurs when a number of individuals attempt to synchronise their responding, as in a rowing eight, where the externalisation of potential cues for coordinating individual timing provides valuable hints as to the underlying mechanisms.

Research into the variability of timing has been complemented by analyses of force variability. This has developed into a concern with temporal coordination between grip force used to hold an object and forces created in moving the object in the environment. Subtle adjustments in grip force have been demonstrated that anticipate changes in forces acting on the object being gripped. Similar finely tuned relations between natural reaching and hand-shaping also cast light on the subtle link between perceptual factors and the anticipatory control of action. The breakdown of such processes following stroke, cerebellar disease or in utilising an artificial hand, illuminate the underlying mechanisms, and have substantial implications for therapy. Balance during standing presents another example of the interplay of perception and action. Anticipatory and reactive components of balance have been studied using a recently patented device that provides a simple measure of the subject's weight distribution. Together with a newly developed method for disturbing balance by applying a gentle force to the pelvis, this approach will yield useful tools for analysing and helping remediate balance experienced in neuromuscular disorder.

Perception and timing are both crucial to interception tasks such as hitting or catching a ball, or braking to avoid a car collision. While an influential model exists that accounts for these phenomena in terms of a servo system based on a single optical parameter, Tresilian has demonstrated that other models are also consistent with existing data, and has begun to explore both the theoretical advantages and drawbacks of the various models, and to test them empirically.

Future work on control of force and timing of movement will consider the interesting case of bimanual movement, using procedures that load either common, central or lateralised peripheral components of bilateral movements. This work will be complemented by analyses of ensemble timing as it occurs, for example, in rowing. An important aspect of both approaches will be the development of methods for separating long- and short-term fluctuations in movement measures and the evaluation of the roles of local and global information in maintaining coordination of force and time parameters through an extended sequence of coordinated movement.

When subjects make movements, such as raising an arm, that disturb balance, automatic postural adjustments occur. These appear to have important parallels with anticipatory grip force adjustments. The possibility of a common, underlying neural mechanism will be studied via correlations across a range of experimental conditions in normal subjects, and also via evidence of associated deficits in patients with Parkinson's disease, and patients suffering from cerebellar damage. Standing balance will be investigated in stroke patients with a training study that will include conditions designed to improve anticipatory weight adjustment associated with initiation of walking. This work will be complemented by a study of stroke patients who spontaneously develop a maladaptive response to instability and are particularly prone to falling. Finally, research on balance will continue with further analysis of evidence suggesting that certain concurrent mental tasks may interfere with balance, particularly in elderly subjects.

Programme 2: Attention and Cognitive Control

Attention refers to the process whereby an organism controls the flow of information through its nervous system, selecting and coordinating certain stimuli and actions, and inhibiting others. It has continued to form a major component of the Unit's research programme since Broadbent's classic work in the 1950s rescued the concept of attention from decades of neglect. It typifies the Unit's approach to science in drawing on a very wide range of tasks, from the selection of simple stimuli to abilities as complicated as learning a new word-processing programme, and it attempts to tackle the underlying problems using methods with a wide range of analytic levels, from single unit recording in monkeys to the construction of general models of cognitive processing based on techniques of artificial intelligence. We believe that an adequate theory of attention will require a conceptual understanding at all of these levels.

For purposes of exposition, the work can be split into two major groups; one of these is concerned principally with attention as a means of selecting one component of a complex perceptual array. This line of work tends to use comparatively simple tasks, and is already demonstrating the value of combining cognitive psychology with more neurobiological approaches. The second group of studies is concerned with the selection and coordination of action, and has stronger links with the field of cognitive science, with clear implications for the practical problem of understanding people interacting with complex technological systems. It seems likely that both domains rely on broadly similar underlying mechanisms, in which control is exercised by the inhibition or excitation of neural systems; but it is likely that the underlying neural systems involved will prove to differ.

Duncan contributes to both aspects of attention research, with his integrated competition model of visual attention being a good example of the fruitful interaction of cognitive psychology with neurobiology and neuropsychology. Recent work supports the view that visual attention arises through cooperative activation in multiple brain systems, which converge to work on the same visual object The process develops over several hundred milliseconds, as revealed by extended interference between one object and another. Work with Desimone at NIH has used single unit recording techniques in monkeys to study the neurobiological basis of selective attention. When the animal is required to look for a particular object, neurons in the inferotemporal cortex that are associated with perceiving that object appear to be primed, while those associated with non-targets are suppressed. Work using both lesion and PET scanning methods in human subjects provides further evidence for attention as a process involving integrated competition within multiple brain systems. The process of inhibition in visual attention has been simulated by Houghton using a connectionist computational model that is proving influential in the area of memory as well as attention. In experimental work, Lavie has begun to investigate limits over the voluntary control of visual processing.

Complaints of attentional difficulties occur widely in patients suffering from stroke or head injury, and this has led to active collaboration between cognitive psychologists such as Duncan and Lavie, whose primary concern is with the understanding of normal attention, and neuropsychologists from the rehabilitation group. Goodrich has been studying the phenomenon of extinction, whereby a patient may be able to detect a single stimulus in the visual field contralateral to a lesion, but will fail to do so when a second stimulus is present in the ipsilesional field. The tendency to neglect aspects of personal space is one of considerable theoretical activity both within the Unit and more widely, with theoretical developments beginning to generate promising new methods of treatment, some of which will be described in the rehabilitation section. Preliminary studies indicate that visuospatial neglect may be reduced by input from other modalities, and exacerbated when overall cognitive load is high. We propose to develop and teach coping strategies based on these findings.

Duncan and colleagues hope to increase the extent of interdisciplinary collaboration, combining models and techniques from cognitive psychology with a range of psychophysiological measures, including PET scanning and fMRI measures. The work with Desimone will continue, using single unit recording to investigate the neurophysiological and anatomical basis of attention. Questions to be addressed include the nature of competition both within and between visual systems, and the separability of visual and spatial aspects of attention. A panel of patients with clearly specified lesions is currently being formed, and comparisons will be made between patients with parietal, occipitotemporal and frontal lesions to test hypotheses about the various processes underlying selective attention.

While attention has been regarded as a legitimate topic of investigation within psychology for at least 30 years, the related issue of the nature of consciousness has, until recently, been treated with more scepticism. However, evidence from the laboratory and the neuropsychological clinic from such phenomena as blindsight (the capacity of some cortically blind patients to process visual information in the absence of visual awareness) and implicit learning in amnesia have forced cognitive psychologists to come to terms with the need to develop theories of conscious awareness. Marcel, whose earlier empirical work contributed to the acceptance of consciousness as an important topic within cognitive psychology, has been devoting a good deal of his time to both theoretical and empirical work concerned with the question of whether consciousness should be regarded as unitary. Marcel takes several different lines of his work to suggest a division between phenomenal experience and higher-order reflexive consciousness. This second aspect of consciousness is closely linked to focal attention and self-monitoring, and plays a role in what we can report and what gets consciously remembered. The lack of access between these levels of consciousness can be seen as underlying research on anosognosia, where a person is unaware of a neurologically acquired deficit. Work with Tegnèr in Stockholm has shown that patients with anosognosia are not simply confused, but that their degree of awareness of their deficit may depend crucially on the way in which the relevant information is probed.

A related aspect of conscious awareness is that involved in reporting bodily sensations, a capacity that is very important in medical diagnosis, but little studied. Future work will further investigate the capacity of subjects to localise pain, and will further develop Marcel and Tegnèr's anosognosia scale as a general clinical instrument.

The breakdown in monitoring mechanisms found so strikingly in cases of anosognosia has clear parallels to the need to monitor our own abilities in everyday life. Self-monitoring played an important role in a recent attempt to minimise anaesthetic accidents by encouraging anaesthetists to participate in an anonymous incident-reporting system. Sellen has begun to investigate some 3,000 such reported incidents, developing a categorisation system as part of an attempt to understand the errors and reduce them. The most frequent incidents appear to be simple slips ("the wrong drug problem") associated with haste and distraction. The analysis is continuing and a more detailed observational study is being carried out in association with Papworth Hospital.

Understanding such slips of action requires a theoretical framework that is capable of dealing with attentional control as part of the coordination of action needed to perform complex tasks. Duncan's work in this area stemmed from a study of driving behaviour, but has in recent years concentrated on conceptualising and studying the way in which actions are controlled and scheduled. Again he has used a range of approaches, from the study of goal neglect in laboratory tasks, through studies on patients with frontal lobe lesions, to individual differences in general intelligence. Evidence from PET studies, from lesion studies and from the laboratory all indicate the importance of frontal lobe systems in setting and monitoring goals, and in the processes underlying differences between individuals in general intelligence.

Future research will extend the work on patients with clearly specified lesions, and will utilise dual task methodology to develop a more precise understanding of the nature of executive control. It is planned to combine carefully selected tasks with PET scanning, in order to investigate whether executively demanding tasks place demands on specific areas of the frontal lobes, to what extent they limit performance by common demands on content-specific areas, and to what extent a demanding task is simply one that requires many different functional areas.

The nature of executive control is a particularly important issue in attempting to understand how people perform complex tasks such as those involved in human-computer interaction. This area has been extremely active in recent years, with Barnard playing a particularly central role in ESPRIT programmes, and Richard Young being heavily involved in both the Alvey and Joint Councils Initiative in Human-Computer Interaction. These programmes have brought opportunities, but also incurred substantial logistic costs, from the need to coordinate large international teams, and to operate with other disciplines and with colleagues in industry. At a practical level the programmes have concentrated on the analysis of complex technological tasks such as understanding the utilisation of a new word-processing programme, or analysing the way in which experienced or naïve users might interact with a new computer system. The aim is typically to provide ways in which software designers can be made aware of the limitations of the user, so as to design systems that are user-friendly. Both Barnard and Young have tackled this task by developing high-level models of the way in which people cope with complex tasks.

Barnard has developed a model, Interacting Cognitive Subsystems (ICS), that conceptualises the user in a way that was originally developed for understanding language use, but has subsequently been substantially extended. (See also section on Cognition and Emotion). Within the attention and cognitive control programme the basic extensions have focused on the interpretation of visual scenes. In one of the more practical studies making use of such theoretical extensions, the ICS system was taught to human factors students, who proved to be able to use it effectively, given the appropriate task-description vocabulary. They did not need to understand the underlying theory.

Dissemination is clearly an important issue, and the work has been widely presented and is beginning to appear in text books for software designers. Much of the work in this area is disseminated electronically through Internet, a process that allows dissemination to be monitored. Hence we know that in the last five months there were 1,160 requests for documents from this project. Most (740) were from the various collaborators, but there were some 420 requests from unrelated investigators from a total of 18 different countries. It is becoming clear that this will be an increasingly important method of scientific dissemination, particularly for items such as computational models which are not readily communicated within the current journal system.

Over the next five years, Barnard will be devoting a rather larger amount of his time to applying his model to the study of cognition and emotion, but will continue to operate within the general area of executive control, making the model available in tutorial form, and collaborating in a venture to specify the theory in more formal terms. Future empirical work will concentrate on the task of searching iconic arrays, and on the way in which information is coordinated across sensory modalities.

Young has also used human-computer interaction as a test-bed for a more general conceptualisation of cognitive function, in this case based on the SOAR architecture developed in the U.S. by Newell. The model has a highly constrained architecture, and uses learning and problem solving procedures to tackle a wide range of cognitive tasks. It has been applied by Young and his colleagues in recent years to study the mistakes made by subjects first encountering a Macintosh computer, and to demonstrate the role of mental models in using simpler devices such as calculators. Work with Logica, a major British information technology company, has been concerned to develop methods of assisting software designers in creating usable systems.

Future work will concentrate on using the model to conceptualise the representation of task goals, and to provide a better understanding of the way in which people operate within the visually-based systems that are becoming increasingly dominant within HCI.

At a more theoretical level, Young will be concerned with comparing the way in which different conceptual models within cognitive psychology account for the same phenomena. For example, although the concept of working memory plays an important role in SOAR, different assumptions about working memory are made by SOAR, by Barnard's ICS, and by Baddeley and Hitch's working memory model. It would be valuable to know which of these differences are largely notational, and which reflect incompatible but testable basic assumptions.

The final component of this section concerns the Unit's work on driving, a topic that we have studied for many years, but which has now lapsed with the retirement of Brown and the departure of Groeger. The group has been very active and well supported over recent years, when they have been paying particular attention to the process of learning to drive. One important finding from their careful analysis is the huge difference in amount of practice that occurs across different subcomponents of driving skill. Typically subjects have a great deal of practice on control skills, but much less on skills of decision, particularly about situations in which they need to assess what other road users will do. This work was accompanied by another programme concerned with the judgement of risk, demonstrating that video traffic scenes provide a valid means of assessing the capacity for risk judgement. There are clear implications for ways in which driver training should be changed, and of methods whereby decision processes may be practised and subsequently assessed. Groeger has now moved to the University of Leeds where, I am happy to note, the programme will be continuing.

Though our commitment to the analysis of complex, real-life tasks remains strong, with the termination of work in driver behaviour, and Barnard's increasing commitment to cognition and emotion, overall effort in this area is somewhat diminished. At the same time, the neurobiological aspects of the attention programme are increasingly promising, and complement developments in cognitive neuroscience in Cambridge with establishment of the MRC Brain Repair Centre, the Wolfson Functional Brain Imaging Centre, and the Innes Centre for primate neuropsychology. Through collaborations with these other Cambridge groups, and elsewhere, we expect lively developments in this aspect of the attention programme.

Programme 3: Memory

The capacity to learn and remember plays a crucial role in human cognition, and has always formed an important area of research at the APU. Five senior scientists contribute to the area, although only Bekerian and Baddeley would probably regard themselves as primarily working on memory. Consequently, the boundaries between this and other Unit programmes are often indistinct. For example, much of the research on working memory could be categorised as part of the attentional project, while research on prospective memory and on test development is highly relevant to similar concerns within the rehabilitation group, as is Maylor's work on memory and ageing, and Murre's modelling of amnesia, which ties in directly with theoretical work on rehabilitation by Robertson. Links with research on language are equally obvious; a good deal of Bishop's work is related to short-term and working memory, while Patterson's work on semantic memory forms part of her general interest in language. Finally, Bekerian's work again ties in very clearly with the theme of cognition and emotion.

Human memory can be regarded as an alliance of separate but interacting systems that have in common the function of storing information and subsequently making it available when needed. It can be broadly divided into short-term or working memory, involved in the temporary maintenance of information being used to perform other cognitive tasks, and long-term memory. Long-term memory itself can be subdivided into episodic memory, the capacity to recollect specific experiences, and semantic memory which can broadly be regarded as knowledge of the world. Finally, in recent years it has become increasingly clear that we need to distinguish between the previously-described systems which provide information that is explicitly available, and implicit learning and memory, involving the learning and retention of skills and access to information under conditions where the subject may demonstrate learning by performing a task more efficiently, without necessarily having any recollection of the learning experience. Work at the Unit has addressed all of these areas.

Baddeley and Andrade have been concerned with developing a model of working memory originally proposed in 1974 by Baddeley and Hitch. Work has concentrated on two components of the model, namely the phonological loop, a system for temporarily maintaining speech-based information, and the central executive, a limited capacity attentional control system.

Much of the work on the phonological loop has been designed to test the hypothesis that it has evolved as a mechanism for language acquisition. Work carried out in collaboration with Papagno and Vallar in Milan, and Gathercole in Bristol, supports this view by showing that: (1) Adults with a neurologically acquired phonological loop deficit and children with a developmental deficit both have difficulty in acquiring new vocabulary. (2) Normal children show a clear association between a task involving immediate phonological repetition and vocabulary development. (3) Variables that are known to interfere with the operation of the phonological loop also interfere with the acquisition of novel vocabulary, but not with the capacity to learn to associate pairs of meaningful words. We are currently testing the hypothesis that the same system is necessary for the acquisition of grammar.

The central executive is the term applied to the system that is assumed to control working memory. It is a complex and almost certainly multi-component system. We are investigating it by splitting off individual executive processes, which we then analyse with a range of methods involving both neuropsychological patients and normal subjects.

One postulated function of the executive is to coordinate concurrent tasks. This has been studied in collaboration with Spinnler, Della Sala and Logie in Milan and Aberdeen, principally using studies of patients suffering from Alzheimer's disease (AD). The method involves titrating the level of difficulty of concurrent visuo-spatial and verbal tasks to a point at which patients and controls are performing at an equivalent level on each task alone. When combined performance is required, AD patients show a disproportionate decrement, whereas the normal elderly show no such effect. As the disease progresses, dual task performance deteriorates substantially more rapidly than single task. We have also modified our original methodology so as to provide a simple paper-and-pencil version, and have replicated our original results. We are now beginning to explore the generality of this deficit and find that it is also present in a particular subsample of patients with frontal lobe damage.

Other executive processes already investigated include random generation, in which the subject is required to produce an unpredictable stream of responses, a task that appears to load heavily on the executive. More recently we have been investigating the processes involved in responding to stimuli while ignoring irrelevant items presented within either the same or a different modality. Preliminary results suggest that the capacity to resist within-modality interference is particularly susceptible to the effects of ageing.

In the area of long-term memory, much of Baddeley's work has been concerned with collaborative research on rehabilitation, and with the development of improved memory tests. These have included a test of semantic memory, based on both speed of comprehension and capacity of vocabulary, while a second test measures episodic memory performance. Visual and verbal recall and recognition are tested using naturalistic material, comprising coloured photographs of doors and sets of people's names. Preliminary results suggest that the test is highly sensitive, is good at differentiating visual and verbal memory deficits, and furthermore, is enjoyed by the patients. Future research by Baddeley on working memory and long-term memory will form the substance of a separate proposal for work to be carried out elsewhere.

Research by Maylor has been concerned with analysing the cognitive changes that accompany normal ageing. A theme underlying much of her work has been the extent to which ageing represents a general overall decrement, and to what extent certain cognitive functions may be disproportionately impaired or preserved. One series of studies required subjects to make judgements about pictures of objects or people, and to produce the appropriate name. Older subjects uniformly tended to respond more slowly, but this deficit was disproportionately large when naming was required. This effect seems to represent the more frequent occurrence of "blocking" in the elderly, where the name was on "the tip of the tongue". Such a deficit was not found in a selected group of young and elderly experts. Participants in "Mastermind" appeared to show no effect of age on response time, suggesting that up to a point at least, expertise can counteract the slowing in retrieval.

Another area in which the elderly seem to be disproportionately impaired is in experimental studies of prospective memory; remembering to do things. Even when they have demonstrated that they remember the relevant instruction, elderly subjects are still more likely than the young to forget to carry it out when tested under laboratory conditions. Under real-life circumstances however, the elderly tend to be rather better than the young since they make more systematic and effective use of reminders and memory aids.

Maylor's future work will further investigate the area of prospective memory, in particular focusing on factors that may make this function particularly susceptible to the effects of age, such as the need for self-initiation of action, the demands of concurrent activity, and the extent to which environmental cues can prompt recall.

Other research will be concerned with further analysis of the effect of age on retrieval from long-term memory. Finally in collaboration with Wing, she will study the interaction between extent and type of concurrent cognitive activity and postural stability, an important practical problem in the elderly.

Prospective memory also featured in a study carried out by Sellen at Rank Xerox, on memory problems in the workplace, where prospective memory lapses proved to be the major source of reported memory problems. This study led to the development of a new computer-based reminding system that is currently under development by Rank Xerox. The technological capacities of Rank Xerox also allowed Sellen to carry out a more theoretically-based study on factors influencing the prospective memory task of remembering to press a button every two hours, a simulation of pill-taking. Subjects wore an "active badge" that monitored their location and their responses. The results suggest two separate components, one concerned with self-prompting and a second dependent upon environmental cues. Further work will use this technology to study the effect of a range of variables including the extent to which the subject "worries" about performing the task. If successful, the device may well prove useful in studies of cognition and emotion.

The classic topic of memory research is episodic memory, the capacity to recollect a specific experience. This is the focus of the research by Bekerian, who is particularly interested in the study of memory under the naturalistic circumstances that occur when a witness attempts to recall a dramatic incident such as an attempted rape, or a series of incidents such as repeated physical or sexual abuse. Evidential testimony represents a situation in which it is essential to assess the accuracy of recollection, and to avoid the danger of distorting memory through the process of interrogation. Bekerian has investigated aspects of testimony that influence the degree of perceived authenticity, including consistency, spontaneity, and the presence of reported perceptual detail. These features were modulated by the method of reporting; for example, certain interrogation methods encourage the subject to try to visualise the scene, and there is evidence to suggest that this leads to more perceptual detail, some of it erroneous. Such detail may then give rise to an unwarranted increase in the confidence of the witness and the preparedness of a juror to accept the report. Other factors influencing accuracy include whether recall is spoken or written: written recall seems to lead to a reduction in correctly recalled information, possibly because the more formal response mode encourages a more "polished" product.

Bekerian has worked extensively with the Home Office, the Police, the County Statutory and Caring Agencies and the Regional Health Authority, all of whom are concerned to improve their quality of interviewing, particularly in areas such as that of child abuse. Interviewing for therapeutic or evidential purposes demands very different styles, with the Home Office stipulating that therapeutic-style interviewing should not be used to obtain evidence. Bekerian's work on the analysis of interviewer behaviour has led to many requests for advice in developing better training of interviewers. Currently, the Crown Prosecution Service are forced to abandon a large number of cases on the grounds of inadequate interview procedure. Such statistics should provide evidence of the success of our attempts to improve interviewing skills.

Investigation into methods of evaluating the accuracy of testimony, and of avoiding distortions during the interview process, will continue. The commonly used "cognitive interview technique", which among other things encourages the use of imagery, is based on theoretical memory research, and does appear to be an advance on previous techniques, but is almost certainly capable of improvement.

New lines of development include the reviewing of current practice in investigating serial crime, including the technique known as offender profiling. Bekerian has been requested to compare approaches in Britain with those in the USA, Continental Europe and Australia, and it seems likely that this may well give rise to further empirical work. Finally, a joint interest with Dalgleish (who is about to join the Cognition and Emotion group) concerns the influence of emotion on the memory of patients suffering from post-traumatic stress disorder, in which persistent vivid memories of the incident often form one of the more distressing symptoms.

While episodic memory may be the most striking and characteristic aspect of human memory, semantic memory which comprises the repository for our knowledge of the world is equally important. Karalyn Patterson has been studying semantic memory in collaboration with Hodges of the Neurology Department at Cambridge. They have concentrated on three issues: the anatomical localisation of the system responsible for semantic memory; whether semantic and episodic memory represent genuinely separable systems; and the functional organisation of semantic memory. The work is based on longitudinal studies of the decline of semantic memory in two types of patient: Alzheimer's disease (AD) patients, in whom a prominent episodic memory deficit is usually associated with a subsequent decline in semantic processing; and patients with a recently labelled syndrome of semantic dementia, in whom the semantic deficit occurs in a relatively isolated form. Brain imaging studies suggest that the temporal neocortex is particularly important for semantic memory, while differences in the specific location disrupted in the two patient groups hint at the possibility of anatomically separable semantic and episodic systems. Further investigation of this issue will depend upon a more detailed analysis of episodic memory in semantic dementia cases; the issue is not straightforward since, even if semantic and episodic memory reflect separate systems, there is no doubt that they interact.

A study of the breakdown of semantic memory in patients with semantic dementia suggests a consistent pattern, with specific information (such as the fact that dogs bark) being lost before more general information (e.g. dogs are animals). This is compatible with a widely-held hierarchical concept of the structure of semantic memory, but is also open to other explanations. Differences in number of relevant features in a distributed network could make the higher level concept of animal more redundant and hence more robust to partial disruption by brain damage.

Future plans include serial in vivo imaging of semantic dementia patients, followed by neuropathological analysis at post-mortem. Such a strategy will also be pursued with AD patients, with the additional aim of relating the more varied pattern of deficits in these patients to the localisation of neurodegeneration. The issue of whether the decline in semantic memory represents loss of basic semantic representations, or impaired access to relatively preserved representations, will be tackled using measures of consistency across successive tests, an approach that raises some challenging statistical issues. Finally, in addition to detailed exploration of semantic and autobiographical memory in patients during the early stages of decline, it is proposed to develop methods that will allow semantic processing to be assessed during the later stages of dementia. Work by Jean Mandler in San Diego on pre-linguistic babies employs a measure of the time that a baby will spend looking at an object as an indication of its degree of perceived novelty. When four items from a similar general category, for example living things, are presented in succession, presentation of a fifth living thing leads to shorter inspection than presentation of a non-living object. Using this technique, Mandler has shown that babies acquire the living/non-living distinction at a very early age. Patterson and Hodges predict that this distinction will be robust in dementia patients.

Andrew Young, who recently joined the Unit, is also concerned with semantic memory, but is particularly interested in the way in which people are perceived and remembered. Having previously concentrated on face perception, he is interested in the extent to which memory for known faces uses the same underlying cognitive and neural structures. One way of studying this is through an analysis of prosopagnosia, a deficit in face recognition that occasionally results from brain damage. His work has identified at least two types of patient, both of whom experience great difficulty in recognising familiar faces, but who differ in their capacity to generate images of faces. One type of patient is able to form accurate images of faces which are no longer recognised, and hence can answer questions about the appearances of pre-morbidly familiar people, whereas the other has no capacity for imaging faces. This pattern of results suggests a multi-stage system for recognising faces, as do other results obtained before his appointment to the Unit by Young and his co-workers demonstrating that some prosopagnosic patients show implicit recognition of famous faces that they do not report as familiar. This can be demonstrated by showing that presentation of a non-recognised politician's face will influence the subsequent recognition or categorisation of his name.

Future work will develop new techniques for testing the theory both with normal subjects and with patients. Prosopagnosic patients are rare, but it is commonly the case that patients suffering from anterograde or retrograde amnesia have difficulty in face recognition. A detailed examination of such patients will first of all identify any for whom face recognition problems are particularly marked, and will then check whether the deficit is one of recalling the person, which would be reflected in a parallel difficulty in recognising a voice or providing information about a named person, or is specifically visual.

Further studies will exploit the fact that people represent an interesting class of semantic concept, since their visual appearance changes as they age, and new facts about them are being constantly learnt. This allows a test of one of the classic issues of concept formation, that of whether concepts are based on a large number of stored instances, or represent an abstraction from the individual experiences. The former might suggest that it would be easier to associate a picture of a person's face when young with information from that time, (e.g. that Cliff Richard sang "Living Doll") than it would be to associate an early photograph with a more recent piece of information.

A prominent feature of the Unit's work on learning and memory over recent years has been an increasing interest in computational, and in particular connectionist, modelling techniques. This powerful new modelling approach, combined with the judicious use of empirical data, allows much more detailed and ambitious models than were possible using a purely descriptive conceptualisation. Interestingly, there are close affinities between recently developed connectionist models of human learning and earlier mathematical models based on conditioning in animals. Work by Shanks has shown that an associative conditioning model of this type gives a very good account of whether human subjects perceive pairs of events as causally related. Shanks has also explored connectionist models of category learning, demonstrating major problems with a standard learning algorithm, back-propagation, and proposing an alternative connectionist model that avoids these difficulties. Murre has been developing a general connectionist model of long-term memory and forgetting. He begins with the problem of massive interference that occurs in some basic back-propagation models, spelling out a number of ways in which this can be avoided. He has been particularly intent on ensuring that his model is biologically plausible, with the result that it has formed the basis for a collaboration with Robertson to generate the framework for a general model of rehabilitation. Concern with neuropsychological data has led to the first connectionist model of learning that also gives a good account of both anterograde and retrograde amnesia. Research on forgetting has been comparatively neglected over the last 20 years, and Murre's model should provide an excellent basis for a revival of interest in this important topic.

One final area in which connectionism has influenced the Unit's work is in attempts to model the phonological loop component of working memory. Norris, Page and Baddeley, funded by the Joint Council's Initiative in Cognitive Science, are capitalising on the fact that modelling the loop involves two of the fundamentally important issues of connectionist modelling: (i) how to represent serial order; (ii) how to capture the process of chunking whereby individual units are aggregated to form larger units, which many models assume to be the basic process of long-term learning. Extensive existing data place valuable constraints on possible models. In addition to developing a connectionist model that gives a good account of the initial data set we have also developed a more abstract mathematical characteristic of the serial recall process which not only gives a precise quantitative account of the data but also helps specify a set of properties which must be possessed by any adequate model of serial recall.

The next issue is that of obtaining a deeper understanding of simulations by mathematical modelling. Houghton's competitive queuing model, initiated at the Unit and subsequently developed at University College London, has been influential in modelling development. Future work will elaborate the mathematical analysis of the connectionist model, and will concentrate on the question of how items are represented in memory, and how the serial recall process avoids the inappropriate repetition of earlier items while at the same time being able to cope with sequences in which the same item occurs more than once.

Programme 4: Language and Communication

This area which is central to the study of cognitive psychology continues to form a major component of the Unit's programme. Our approach is characterised by the utilisation of a wide range of techniques and subject groups, and by the attempt to blend pure and applied research.

Cutler, who has now left to become a director of the Max Planck Institute for Psycholinguistic Research, and Norris are concerned with the problem of how we segment the continuous stream of a spoken utterance into its constituent words. They tackle the problem using standard experimental paradigms, computational modelling and cross-linguistic studies. A basic hypothesis, the Metrical Segmentation Strategy, proposes that prosodic information is used to segment the speech stream, with the details of the strategy depending on the specific language. English rhythm is based on the foot, French on the syllable, and Japanese on the mora (typically a consonant-vowel unit). Stressed vowels have been shown to be longer, louder, and greater in pitch movement

than unstressed syllables, while a detailed analysis of the stress pattern of English indicates that a high proportion of words have stress on the initial syllable, making it a valuable cue to segmentation in English.
The Metrical Segmentation Strategy is utilised by Norris's computational model SHORTLIST, which represents the first new model of speech perception for over a decade. Unlike its major competitor, the TRACE model of McClelland and Elman, Norris's model does not require the duplication of processing networks, and does not assume an interaction between processing levels. His computational model is simpler in assuming only a billionth as many inhibitory connections, and is able to cope with a vocabulary of over 20,000 words, as opposed to 1,000 words for the TRACE model. The model has been shown to account for existing data well, and has been tested empirically in a series of studies in which subjects were instructed to detect words embedded in other words, for example the word CAM in CAMEL, where the results are compatible with the assumption of competition between word representations as proposed by the SHORTLIST model.
Collaborative work between Cutler and Jusczyk has shown that young infants from English-speaking families prefer to listen to words with stress on the initial syllable, suggesting that lexical segmentation is being acquired at a very early age. Future work will evaluate this further, using statistical simulation of the learning process, and utilising the model to investigate the nature of segmentation in more detail. There is, for example, evidence that subjects also make use of statistical characteristics of syllable and word endings. Two basic assumptions of the SHORTLIST model, namely the modularity of its component processes, and its bottom-up rather than interactive architecture, will be subjected to more rigorous empirical test. Finally, studies of the role of syllabic information in lexical representation will be extended to native speakers of French and Dutch in order to assess their cross-linguistic generality.
Karalyn Patterson also uses connectionist modelling and cross-linguistic methods to study word recognition and production, but relies more heavily on neuropsychological evidence than do Norris and Cutler. She is particularly interested in the interaction, in various language tasks such as reading aloud, between representations of a word's orthography (spelling), phonology (sound or pronunciation) and meaning. A major component of her work involves study of the breakdown of language in patients suffering from progressive neurological disease, a programme that is carried out jointly with Hodges from the Department of Neurology in Cambridge. Patterson and Hodges have been particularly interested in "semantic" dementia, a neurodegenerative condition involving focal atrophy of temporal neocortex. Because this condition produces relatively selective loss of semantic memory, it offers the opportunity to study the impact of loss of word meaning on other aspects of language processing. For example, the fact that patients with semantic dementia develop surface dyslexia (a reading disorder producing regularised pronunciations of words with irregular spelling-sound correspondences, e.g. reading pint to rhyme with "mint") suggests an important interaction between meaning and phonology in reading.
Work on normal subjects has also been concerned with the interaction between orthography, phonology and meaning. Recent work by Patterson and Strain has demonstrated that the speed and accuracy with which normal adults read written words aloud is affected not only by the word's frequency and typicality of spelling-sound correspondence, but also by a semantic variable, imageability (low imageability words are abstract, high imageability words refer to concepts with many sensory/motor properties). This result again implicates word

meaning in the transcoding from orthography to phonology, a task which does not, on the face of it, demand access to meaning. The nature of this transcoding has also been studied in native readers of Japanese kanji, a writing system completely different from alphabetic English, to yield insights into aspects of language processing which are universal and those which are tuned to language-specific characteristics.

Results from normal and impaired English readers play a vital role in evaluating computational models of the transcoding from orthography to phonology. Whereas Norris' connectionist reading model is principally concerned with simulating normal readers' response times to name words under laboratory conditions, Patterson's collaborative work (with McClelland and Plaut in Pittsburgh and Seidenberg in Los Angeles) focuses on the capacity to simulate a range of neuropsychological reading deficits. The model does not yet have a semantic component but is capable, after extensive training, of correctly pronouncing virtually all monosyllabic words, even low-frequency irregular words. When "lesioned", however, it does not successfully simulate the pattern of reading performance typically observed in semantic dementia -- preserved naming of regular words and nonwords, impaired and frequency-modulated naming of irregular words. If the training of the model is stopped at an earlier point, however, a better match to surface dyslexia in semantic dementia is obtained. Future work will explore the hypothesis that degree of skill in spelling-sound transcoding is determined in part by interaction with word meaning.

A third approach in Patterson's work on language has involved PET scanning, in collaboration with Wise and Price at the MRC Cyclotron Unit and Howard at Birkbeck College, London. Studies of both spoken and written word recognition in normal subjects have revealed maximal rCBF increases in regions at or very near those implicated by lesion studies. A novel finding is the effect of rate of spoken word presentation: although most areas of bilateral temporal cortex show monotonic increases in rCBF with increasing word rate, Wernicke's area (known from lesion studies to be specialised for spoken word recognition) is maximally activated even at slow rates. Future functional brain imaging work will take advantage of the fact that techniques are now capable of dealing with single-subject data, making neuropsychological case studies feasible. The role of the right hemisphere in language processing will be investigated with single-subject data from normal subjects and patients with a variety of sites/sizes of left-hemisphere lesions.

Further work on semantic dementia will concentrate on the role of meaning, not only in language tasks (such as word and sentence repetition, and lexical decision), but also in non-language abilities such as object recognition. The progressive decline of language and other cognitive abilities in Alzheimer's disease also provides a valuable source of information about the interaction between different domains of representation. The completion of a three-year longitudinal study carried out jointly with Hodges, with approximately 30 Alzheimer's patients tested at six-monthly intervals on a wide range of tasks, will yield a rich database for hypothesis testing on the structure of language and its decline. Work with Tyler (at Birkbeck College, London), using on-line measures of spoken language processing, is beginning to provide significant advances in the study of both the nature of the meaning loss in semantic dementia, and the separability of semantic and syntactic components of language.

New work will concern aspects of speech production in patients with another form of neurodegenerative disease -- progressive nonfluent aphasia -- involving deterioration of phonology and syntax but relatively preserved single-word meaning. Similar longitudinal analyses will be made of patients with progressive anomia, whose spontaneous speech is fluent but "empty" of specific content words. Our current studies constitute the first systematic experimental analysis of progressive nonfluent aphasia, and both types of patients are yielding results germane to models of speech production. Collaborations with neuropsychological colleagues in Japan will once again enable evaluation of the generality or language specificity of some of these findings. For example, the reading performance of Japanese patients with semantic dementia will be assessed for parallels with surface dyslexia in English.

While Patterson is using the breakdown of language in neurodegenerative disease as a way of understanding its normal operation, Bishop is learning about language processing by studying failures of acquisition in children with specific language impairment (SLI). Although SLI is a clinical problem of some magnitude, it is still poorly understood, being associated with a relatively wide and varied pattern of symptoms. Bishop has used a twin study to investigate the aetiology of SLI, the existence of sub-types and their cognitive basis. Some 90 pairs of same-sex twins were selected on the basis that at least one of the pair has significant language problems, performing at or below the 10th centile on one of four carefully-chosen language tests. The importance of an inherited factor was indicated by the higher concordance (54%) in monozygotic than in dizygotic twins (30%). There was no clear association with other medical problems, other than toxaemia, a poorly-understood disease of pregnancy which may possibly be serving as a marker for other immunological abnormalities.

Future work in this area will use the twin study method to try to obtain a better definition of the SLI phenotype, in particular attempting to decide whether it represents a qualitatively distinct disorder, or a quantitative departure from normality. The issue of heritability of language skills in the normal range will be investigated by testing a normal sample of monozygotic and dizygotic same-sex twins. Data from the SLI twin sample will be further analysed to study the link between language, literacy, motor development and handedness. This sample will also be used to try to identify the best marker for SLI, in particular testing Tallal's proposal of a deficit in rapid serial processing, Gopnik's suggestion that syntactic problems are fundamental, and the proposal by Gathercole and Baddeley, and by Bishop herself, that a deficit in working memory might be critical.

One problem in dealing with SLI is that of identifying some of the subtler components of language deficit. In "semantic-pragmatic disorder" the child is fluent but verbose, showing poor comprehension and a tendency to interpret language literally, together with difficulties in the more social aspects of conversation such as turn-taking. Bishop and Adams in Manchester are developing a method for conversational analysis that aims to pinpoint such problems, using precise and reliable coding. Future work will investigate the extent to which a deficit in social interaction might be fundamental, using tests of nonverbal behaviour and "theory of mind" tasks taken from the study of autism. Preliminary evidence is not encouraging for these hypotheses, however, suggesting the possibility of some form of more general attentional deficit. It is proposed to modify some of Duncan's tasks for use with children so as to investigate the attentional deficit hypothesis.

Preliminary work on the grammatical deficit in SLI suggests that it does not represent a systematic and specific deficit, since the same grammatical rules will be followed on one occasion and broken on another. The fact that the likelihood of error increases with the length of utterance suggests that the difficulty may be a limitation of general processing resources. Future work will test this in a number of ways. SLI children will be required to repeat sentences varying in length, with and without inserted errors, and will be required to judge their grammatical correctness. This will allow a more precise test of the hypothesis that errors occur when processing load is high. Another way of testing this hypothesis is to combine sentence repetition with a demanding non-verbal task; again the prediction is that grammatical errors should increase in SLI children. Finally, it is proposed to use the methods of language analysis developed from SLI children to study language and communication in a wider range of conditions. For example, work with Skuse at the Institute of Child Health in London will apply the methods of conversational analysis to children suffering from Turner's syndrome, who typically show a mature interactional style but have difficulty in making friends, suggesting a subtle deficit in social interaction.

The more complex communicative aspects of language are also the concern of Wright, although in her case the focus is on written communications rather than with face-to-face spoken interactions. When people use written materials to accomplish a task they need to find the relevant information, understand and remember it, then act on that information. Changes in document design can be used to explore how people integrate these cognitive activities. One component of Wright's programme, concerned with issues of understanding, has examined the way in which readers and writers use such graphic supports as sketch maps and diagrams. She has found two kinds of graphic-text relation that differ in their effects on comprehension if readers study the illustrations while reading the text. Graphics explaining textual details can hinder readers trying to follow the main thread of the text; graphics that offer an organising schema for the text repay study during the course of reading. However, readers do not distinguish these graphic roles and adopt a single strategy of studying the graphics either before or after reading. Document design can encourage readers to change their strategies, allowing the possibility that the design can be tailored to create the optimal reading strategy. However, it was found that writers also adopted inappropriate strategies when giving directions about a route to be taken. They did not spontaneously provide aids such as sketch maps, although they recognised that these would facilitate communication. These studies point to the complexity of the communication skills needed by adults working with written information and graphics.

One situation in which it is often necessary to combine verbal and visual forms of communication is in finding one's way in an unfamiliar environment. Here the focus is on the application of the knowledge gained from reading. In a study concerned with route-finding by patients within a large hospital, provision of a map led to more satisfaction and less re-tracing of the path than relying on the hospital signposting. This occurred despite the fact that use of the map did not lead to more rapid arrival at the destination, because people with the map chose to spend time planning their route and considering alternatives. Thus speed may not always be an appropriate indicator of good information design. Instead, good design needs to meet all the purposes for which people will want to use it. An incidental finding during this research was that one source of problems for hospital signposting is the way in which the same location can be described in different ways, Room C120, the Eye Clinic and Dr Smith's Clinic for example. Emphasising one of these in the appointment letter and using this label on hospital signboards would simplify the problem.

Another component of Wright's programme has examined readers' strategies for finding information within electronic documents where readers can move within the texts in new ways, jumping immediately to related information. Readers compared information from different parts of a text in order to reach a decision. It was found that their choices about how to move within the document were determined by perceptual factors, such as the spatial relation between text windows on the computer screen, even though this sometimes resulted in a search pattern that made it more difficult to remember the information found. Similarly, the inclusion of verbal information in pop-up windows changed its status within the discourse structure of the text and so enhanced subsequent recall. These studies of search strategies show the interplay between information design and readers' allocation of cognitive resources.

Work on creating usable written communications has wide potential applicability, but presents the problem of how such information should itself be communicated to the potential user. Wright devotes a good deal of her time to this issue, contributing to seven British Standards for documentation, and delivering invited talks and keynote addresses to a wide range of professional groups outside psychology. Future research will continue to investigate the roles of graphics in text, extending the work to instructional materials, because the need to create plans for action changes the nature of the dominant cognitive demands on readers, demands which may be met or hampered by animated graphics. When people follow complex multi-step instructions, segmentation into appropriate constituents will help both comprehension and memory. Wright will investigate whether adults do this spontaneously, and if not whether appropriate design can encourage them to do so. A different way of giving instructions is to provide a model of the performance required and ask people to follow it. This technique is often used to encourage people to write in a certain style, although the model given is of the product rather than the performance. This kind of instruction-giving will be explored in order to determine whether people simply imitate the surface features of the model or whether they can abstract the underlying discourse structure.

Work will continue on how people search within electronic documents, but the search tasks will be broadened to include multi-featured targets. Electronic documents allow a rich array of search strategies to be investigated using both verbal and iconic materials, and also a variety of document structures including tabular arrays. This work will contribute to existing theoretical accounts of readers' search activities which have so far considered only printed, linear documents such as student textbooks.

Green is also concerned with the role of communication, and in particular in the analysis of non-linguistic artificial communication systems such as diagrams, tables and programming languages, and their use in the increasingly large array of "information artifacts", such as personal calculators and word processors. Green attempts to identify what he terms "structural features" that are applicable to any well-defined information artifact, from timetables to music scores. The success of his attempt is measured by its capacity to deal effectively with a wide range of very different systems.

For example one desirable aspect of any notational system is that it should be "role-expressive", that is it should allow one to break the system into an appropriate hierarchy of subsystems. Applying this characteristic to the programming languages Prolog and Pascal, Green predicted that Prolog was less role-expressive, and hence should give greater difficulties even to experienced programmers. He tested this by giving programmers specific programs with components snipped out. Their task was to restore the appropriate pieces. As predicted, the Prolog programmers took longer and were more slowed down by increased complexity.

Another study tested the conventional wisdom that graphics communicate more effectively than text. A "box and wire" notation from a widely used graphical programming language (LabVIEW) was compared with a verbal equivalent. It was harder to comprehend and led to more errors, probably because it overloaded the subject's working memory to a greater extent. Another concept from Green's analysis is that of "viscosity", the extent to which a system resists local change. For example, a word processing system might have the characteristics that changing section numbers had extensive knock-on effects, creating problems in the index references etc. Using an existing computer science technique termed "entity-relationship modelling", Green has developed a measure of viscosity. Future work will develop this analysis and apply it to further types of information display, including various forms of graph. Possible ways of dealing with viscosity problems, for example by introducing intermediate levels of abstraction, will be investigated.

The essence of Green's approach is that it should be applicable across a wide range of domains, and future work will involve extending it to new applications. It is proposed to collaborate with colleagues at the University Department of Architecture on computer-aided design (CAD) systems for creative architectural design. A range of small demonstration devices will also be constructed, for example bibliographic systems that illustrate the effects of low and high viscosity. Finally, attention will continue to be paid to the issue of communicating to the wide and varied range of potential users. In particular, it is proposed to develop a teaching package that will illustrate the methods that have been developed, evaluating the package using Open University students.

A final area of research in communication concerns the development by Rank Xerox of videoconferencing systems, and their evaluation. Sellen has compared face-to-face communication with three different conferencing systems, each communicating different aspects of the participants, from voice-only to systems which use multiple cameras. The only major difference observed was between face-to-face conversations and the rest. Conversations mediated by technology all induced a more formal style of interaction, with fewer interruptions and a more studied handover of the floor from one speaker to the next. A related project concerned collaborative working, either face-to-face, or on remote stations linked by up to four video cameras. Subjects sometimes found the additional camera information useful, but had difficulty in reaching a joint frame of reference, underlining the importance of "common ground" in efficient communication. Future work will extend this research to field studies of video links between Welwyn and Venray in Holland for the distributed design and manufacture of photocopiers. The study will be principally observational, and will investigate issues like adaptation to the system over time. It will, however, also be possible to carry out experiments, for example allowing subjects to select amongst different views of the remote site.

Programme 5: Neuropsychological Rehabilitation

This is the newest research area at the APU. It is developing along the lines proposed in our last Progress Report, and approved by the Visiting Subcommittee who recommended additional posts and funding. The recommendation came at a time of considerable financial pressure, and the Strategy Committee decided that the initial development should be funded out of the Unit's existing budget, with an encouragement to return for further funding once the programme was established. We believe that we have reached that point, and will be requesting the additional support proposed.

The programme has made an excellent start scientifically, despite substantial logistic problems. At the time of our last Progress Report, Addenbrooke's Hospital had offered to provide space, as part of an ambitious development of their somewhat limited rehabilitation service. The promised space was, however, reassigned as part of the pre-election campaign to cut NHS waiting lists, and only now after several years of postponement does it seem that we shall finally be moving the Rehabilitation group into adequate accommodation at Addenbrooke's. The proposed expansion of clinical rehabilitation has still not occurred, but fortunately this was less critical than seemed likely because of the substantial increase in strength of the Clinical and Neuroscience Departments at the University Medical School. We have excellent and productive research links with Neurology, Neurosurgery, Psychiatry and Anaesthetics, while the development of the Interdisciplinary Research Centre in Brain Repair and the upgrading of Neuroimaging facilities are likely to strengthen our links with Clinical Neurosciences. Finally, the Lifespan Trust, which is responsible for health in the community in the Cambridge area, plans to develop a model Neurorehabilitation Unit for post-acute patients, with Wilson serving as Scientific Director. In the meantime, Wilson and Robertson have been able to compensate for the comparative paucity of local rehabilitation facilities by collaborating with colleagues elsewhere.

The Rehabilitation group have focused their attention on the assessment and treatment of brain injured people, attempting to analyse the role of neural plasticity and re-learning in their recovery. We have chosen to focus on cognitive deficits in memory and attention since these are both pervasive symptoms of brain damage which are not only intrinsically undesirable, but in addition are likely to interfere directly with any attempt at rehabilitation. They also represent topics that are of central theoretical concern to the Unit, with the result that there is very active collaboration between the Rehabilitation section and colleagues whose work is principally reported elsewhere. Consequently, the question of whether a particular piece of work is reported as part of the work on rehabilitation, or as research on attention or memory, is to some extent arbitrary.

Wilson's work can be divided into three related themes. The first of these concerns the detailed observation of the natural history of recovery from brain injury, which forms a basis for the second theme, namely that of developing better methods of assessment, which in turn feed into the third aspect, improving methods of treatment. Although we know a great deal about the sequelae of various types of brain damage, much previous work is based on cross-sectional studies, with very little attempt to monitor the same patient over a substantial period of time. Wilson has been carefully following up patients that were seen and studied in depth during her period at Rivermead Rehabilitation Centre, Oxford (1979-85). These studies have generated important baseline data regarding natural recovery of function in different cognitive domains, and such data will be crucial for the theoretical understanding of the processes underlying recovery and rehabilitation, and for the practical goal of optimising existing rehabilitation regimes.

One example of this detailed observation of natural history comes in a joint study with McLelland and Shiel at Southampton who used the careful observation of patients recovering from severe head injury as a basis for developing a standardised assessment usable from a state of coma through to the point at which other more conventional neuropsychological tests can be deployed. Particularly during the early stages, signs of recovery can be quite subtle, often resulting in the erroneous conclusion that the patient is not improving. Extensive longitudinal data on 88 patients have been collected, and are currently being analysed with a view to standardising scales that should prove helpful in patient monitoring and in prognosis. Two other lines of research have stemmed from this study. The first concerns the issue of whether learning can occur in coma; evidence suggests that it can, and that it may have implications for training methods that may minimise undesirable features such as contractures. The second has concerned a more detailed analysis of the confusional state known as post-traumatic amnesia (PTA). Length of PTA is commonly used as a predictor of probable outcome, but its accurate measurement is acknowledged to be problematic. Studies at Southampton and subsequently with Boismeir in the Department of Neurosurgery in Addenbrooke's are providing a much more detailed account of PTA, and it is hoped will lead to the development of better methods of assessment.

The developments in understanding of memory function at the APU and elsewhere have furthermore led to the construction of tests which incorporate facets of memory hitherto largely ignored in clinical memory testing, such as, for instance, prospective memory (remembering to do things at the right time). It is perhaps this combination of the use of everyday materials together with theoretical sophistication, which has led to the strongest correlations yet found between a clinical test (in this case the Rivermead Behavioural Memory Test, developed by Wilson et al) and real-life functional memory performance and adjustment.

Wilson and colleagues are pursuing work on this and other facets of the memory system in developing a specific test of prospective memory based on a paper-and-pencil text-based procedure, where the reader must obey instructions at some later point in the text. Preliminary studies in normal ageing on this test are promising. Wilson is also collaborating with Burgess in London and Alderman in Northampton in developing the BADS test (Behavioural Assessment of Dysexecutive Syndrome), influenced by Shallice's work on the frontal lobes and Baddeley's concept of working memory. Preliminary data are encouraging, and norms are now being developed.

In general, this approach to clinical testing which Wilson and colleagues have developed has been very successful and influential worldwide. For instance, the RBMT is now used in some 17 different countries in 11 languages, and versions for children and Down's syndrome have been developed.

In the area of treatment, much of Wilson's work has focused on a technique known as "errorless learning" in which the learning task is structured so as to avoid allowing the subject to make mistakes. This approach was developed in the animal learning field many years ago and has had some application to learning in mentally handicapped people. Its possible value in helping patients with memory deficits was suggested by Baddeley and Wilson, who argue that one of the major functions of explicit episodic memory is that it allows the organism to avoid errors. Amnesic patients who lack this memory system will therefore tend to be captured by their own erroneous responses, with each incorrect response making it more likely that the same error will be made again. An experiment designed to test this prediction indicated that amnesic patients were indeed particularly susceptible to disruption by earlier errors. A series of single case studies have demonstrated that errorless learning can be used with advantage across a range of patients and a range of tasks, from learning names to acquisition of the skill needed to programme a memory aid. It is equally clear, however, that the method does not always work in a simple and straightforward way, and it is proposed over the next few years to explore the theoretical basis of the errorless learning phenomenon at the same time as assessing its generality across patient groups and materials.

A particularly promising potential development over the next few years is the proposal that Wilson acts as Scientific Director to a new Rehabilitation Unit to be created by the Lifespan Trust. The Unit will deal with some 15 post-acute patients during the period between leaving hospital and returning to work. The Unit will be modelled on similar units in the USA and Denmark, and its success will be evaluated in collaboration with Stilwell of Warwick who is currently responsible for the assessment component of the Department of Health National Brain Injury Study. In addition to providing an ideal environment for developing and evaluating rehabilitation practice, the proposed centre offers a promising novel method of interaction between the Council and the NHS.

Robertson's principal concern is with attention and its disorders. His programme of work ties in closely with that of Duncan's group reported in the Attention section, and to a lesser extent with the attentional control components of the work on cognition and emotion. Robertson takes as his theoretical basis evidence from a range of sources, including PET scanning, that suggests that, in addition to the competitive processes underlying attention proposed by Duncan, there is a need to propose the existence of at least three supramodal attentional systems, for selection, sustained attention and spatial orientation respectively. One must also assume that deficits in these attentional systems strongly determine recovery of function following brain damage, given that much recovery of function depends on learning, which itself is heavily influenced by available attentional resources. Robertson has developed a clinical test of these different attentional processes, using the same principles as espoused by Wilson, namely of combining everyday materials with theoretical structure in clinical test development. The Test of Everyday Attention (TEA), using such materials as maps and telephone directories, has a factorial structure (based on a standardisation sample of 154 normals) which indeed supports the PET and other evidence about the existence of separable attentional control systems. Furthermore, in a population of stroke patients, performance on certain subtests of the TEA at two months post-stroke significantly predicted recovery of functional independence and everyday life abilities at eight months post-stroke. This result provides the first evidence of a theoretically-predicted link between attention and recovery of key physical functions following brain damage. The test is about to be published.

In the past, rehabilitation has all too often been based on the ad hoc application of pragmatic techniques aimed at relieving symptoms. Robertson, in collaboration with Murre, has proposed a theoretical framework for understanding the process of neuropsychological recovery, a framework that was strongly influenced by Duncan's work, and by Murre's interest in connectionist models of learning and memory. They suggest four ways in which performance may be disrupted, together with ways of alleviating this disruption.

(1) Overall level of sustained attention or arousal may be too low. They have developed metacognitive, self-instructional methods to train patients to increase sustained attention.

(2) A neural circuit may be malfunctioning, but may be supplemented by the activation of related compatible neural circuits.

(3) The operation of a malfunctional neural circuit may be exacerbated by competition from intact circuits. This inhibitory competition can be reduced by inducing even minimal responses from the impaired circuits.

(4) Subjects may have dysfunctional automatic control of action, but this can be supplemented by the development of conscious strategies.

Evidence for each of these sources of disruption and methods of treatment have been investigated and are being further explored and developed.

The right hemisphere-based sustained attention system may have particularly strong connections with the right hemisphere spatial orientation system which malfunctions in unilateral neglect. To demonstrate improvements in neglect in response to non-spatial sustained attention training would therefore provide a theoretically important piece of evidence as well as a clinically novel and useful strategy for training both unilateral neglect and sustained attention. In a study carried out jointly with colleagues in Stockholm and Southampton, patients were taught a self-instructional procedure that brings phasic arousal under verbal control. After five one-hour treatment sessions, subjects showed reduced neglect, and enhanced performance on the TEA. Another study using an attentional control procedure identical to one used by Teasdale with recovered depressed patients, also appears promising in producing performance enhancement in head injury patients together with self-reported improvement in everyday functioning. Both these lines of research will be followed up using more extensive group studies.

Robertson's work fits closely with Duncan's view of the role of competition and integration of neural circuits in attentional control. One example of this approach draws on the evidence that there are three separate but interconnected spatial circuits for body (personal) space, near-body (reaching) space and far (locomotor) space. Patients who show left neglect following a right hemisphere stroke can be taught to reduce the extent of the neglect by active movements of the left hand in left hemispace. Neglect is not diminished when the movement is passive, or when the left hand moves in right body space, or the right hand is active in either right or left body space. The nature of the action is also critical, with reaching and grasping causing more enhancement than simply pointing. Future work will examine these findings in more detail, in particular separating out neglect of stimuli versus neglect of output. A clinical trial will be carried out in collaboration with McMillan at the Wolfson Rehabilitation Centre, testing a Limb Activation Device which is located in the neglected field and emits a signal at irregular intervals to which the subject is required to respond with the neglected limb. Preliminary results are encouraging, but the planned more extensive study will give clearer evidence of the clinical viability of the method.

Work on reducing competition effects is closely related to the research of Duncan and Goodrich who are studying the phenomenon of extinction, whereby the detection of an object in the contralesional field can be prevented when a competing ipsilesional stimulus appears. Robertson has shown that the extinction phenomenon applies also in the motor domain, and that the neglect-reducing effects of left hand movements are abolished when the right hand is simultaneously moved, as the competition hypothesis would predict.

Robertson has also shown that left neglect patients veer to the right when walking, but that this can be corrected by left hand movements while walking. This result can also be interpreted in terms of the competition hypothesis, namely that the cortical activation underlying the left hand movement, reduces competition from the undamaged left hemisphere of the brain. Robertson proposes to investigate the therapeutic implications of competition-reduction in other areas of perceptual deficit, as well as in non-spatial attentional problems.

In collaboration with Duncan, Robertson will study the problems of attentional control in patients suffering from frontal lobe damage. Duncan's concept of goal neglect will be investigated, and the general framework of competitive circuits used to generate and test methods of attentional control.

Work in this area has so far relied principally upon behavioural measures. The integrated competition model of rehabilitation proposed by Robertson and Murre does, however, make very specific predictions as to the underlying neural consequences of damage and treatment. Robertson and Duncan plan to take advantage of the planned development in PET scanning and fMRI in Cambridge to test the model more directly. For example, it is predicted that left-hand grasping in left visual neglect patients will have effects on bloodflow that extend substantially beyond those of simple motor activation, and that these effects will be abolished when the grasping is bilateral.

Finally, if our research in the area of rehabilitation is to have any impact, then it is essential that it is communicated to therapists who are in day-to-day contact with patients. Many of these will be occupational, speech or physiotherapists who would not be expected to read the psychological literature in which our results are published. For that reason it is essential that Wilson and Robertson devote at least some of their time and effort to dissemination. Both have great strengths in this area and are in constant demand for delivering workshops and addressing groups of clinicians and therapists, as well as receiving many requests for advice on either clinical or research issues. The fact that they are able and willing to provide this vital link with the clinical community bodes well for the future influence of this component of the Unit's work.

Programme 6: Cognition and Emotion

Over the last decade, the Unit has played an active role in linking cognitive and clinical psychology. We have been concerned with the way in which the emotions influence attention and memory, and how they are themselves modulated by such cognitive processes, in the case of both normal and clinical populations. Such a development had two aims, to provide a broader and more complete understanding of cognition, and to help guide the development of better methods of treating emotional disorders. We have made good progress in the first of these aims, which is already beginning to feed through to the difficult, but enormously important second goal.

Mathews and his colleagues in Cambridge and elsewhere have been concerned to understand the nature of the symptoms associated with anxiety, and have studied both patients suffering from anxiety disorders, and also members of the general public who volunteer to participate in studies of "worriers". Anxious patients rate the subjective likelihood of negative events as higher than non-anxious subjects, and are more likely to interpret ambiguous events in a negative way. They are also more distracted by such stimuli; for example when required to name the colour of the background on which a word is printed, anxious subjects are slowed down by the presence of a negative word such as cancer, an effect that occurs even when the word is presented so briefly that it cannot be consciously identified. When the anxiety disorder is treated, then the difference between patients and controls disappears.

Worriers resemble anxious patients in rating the likelihood of bad things happening to them as higher than do control subjects. They are also poorer at giving reasons why such calamities might be unlikely, but when they are successful in doing so, this does influence their estimate of future probability of such negative events, suggesting a possible line of treatment for excessive worry.

Although anxiety has marked and consistent effects on the likelihood of attending to negative events, anxious patients do not consistently show any greater tendency to recall negative items. Nor do they take any longer than controls to decide whether a given word such as cancer is pleasant or unpleasant. This pattern of results suggests an overall hypothesis. It is necessary for survival for an organism to be vigilant for potential sources of threat, and for the level of this vigilance to be increased at times of danger. Patients suffering from generalised anxiety demonstrate a chronically vigilant style in which there is a bias towards the automatic selection of stimuli of a potentially threatening nature, which in turn is likely to increase further the level of anxiety and maintain the bias. Although negative stimuli are preferentially encoded, processing such stimuli in depth may be inhibited, with the result that the bias does not show up in memory measures or in the results of conscious evaluation of words.

Future work will examine in much more detail the nature of the process of detection, contrasting judgements of the pleasantness of a briefly presented word with its direct identification, and studying the effects of a secondary task on the processing of pleasant and unpleasant words by anxious and control subjects. If the bias has its principal effect at a relatively automatic preattentive level, then it should show more strongly in judgements of pleasantness than in word naming; in contrast, a later locus would predict that such a bias would be more obvious when the subject's executive capacity is reduced by the requirement to perform a concurrent task. Other work will be concerned with methods of reducing the biasing effect.

Another line of work, particularly involving Dalgleish who is joining the Unit from the Institute of Psychiatry, will be concerned with the relationship between memory and anxiety. Failure to observe that anxious events are better recalled is less straightforward than might at first appear, and in post-traumatic stress disorder vivid memories of an extremely stressful event such as a rape or an accident can often be one of the more distressing symptoms. As will be clear from the section below, patients may develop a style of retrieval from memory that reduces the level of anxiety in the short term, possibly by consciously inhibiting the memory, but at the expense of longer term adaptation to the stressful event.

Work by Williams identified the tendency in parasuicide patients to have difficulty in retrieving specific autobiographical memories. When asked for specific recollections, such patients typically can only come up with rather general memories, such as "being with my girlfriend". This pattern is associated with hopelessness, with poor performance on a task requiring the production of effective solutions to practical problems, and with poor prognosis; such patients tended to be still depressed some seven months later. Overgeneral memory has now been observed in other centres elsewhere in the UK and abroad. In addition to research on depression and parasuicide, work by Brewin at the Institute of Psychiatry for example, has shown that overgeneral memory is found in women who have suffered sexual and physical abuse. Work by McNally at Harvard has found similar deficits in Vietnam veterans who have post-traumatic stress disorder. The pattern of data emerging from these studies suggests that overgeneral encoding and retrieval even of neutral events represents a long-term cognitive style which may arise early in the development of response to traumatic events. Such a style could be mimicked, however, by reduced working memory capacity at the time events are being retrieved. The combination of a long-term overgeneral memory style and reduced capacity at retrieval is particularly disabling. Williams' work is likely to be important since many cognitive treatments depend on the capacity to access specific memories in order to restructure the self-image, and as part of strategies for training and solving social problems. He has moved to UCNW BANGOR, but is continuing this line of research and continuing to collaborate with colleagues at the APU (see below).

Depression is a major disease, both in terms of the suffering it causes, and because of its economic consequences, in terms of absence from work, and impaired productivity while working. It forms the focus of Teasdale's work which has been strongly influenced by Barnard's Interacting Cognitive Subsystems (ICS) model. Collaborative work between Teasdale and Barnard has led to an important new development which incorporates the influence of emotion on the operation of the model. This has been published as a monograph which is already attracting a considerable amount of interest because of the way in which it provides a fruitful interface between cognitive psychology and issues of clinical practice.

Prior to ICS, attempts to relate cognition and emotion had been dominated by two views, one from a cognitive psychologist, Bower, and the other from a clinician, Beck. Bower conceptualised emotions as additional nodes within an associative net, while Beck linked emotion into a unitary propositional model of meaning. Teasdale and Barnard's model recognises two kinds of meaning, a "propositional" level that allows the manipulation of semantic representations and concepts, and a second more holistic "implicational" level. Affect is directly linked only to the more general level of representation. This implicational level is directly accessed by body state and sensory information, and is responsible for emotionally-held beliefs, which can of course be quite different from what one rationally knows. As a result of experience, we build up complex schemata or models of ourselves, and in the case of depression, such models may well be highly dysfunctional - "myself as worthless" for example. Convincing the subject rationally that this is not true may influence propositional representations, but only experience will create a similar change within more holistic implicational representations. The process of cognitive therapy can be seen as a means of achieving this deeper change.

One line of research has attempted to contrast this view that affect is linked to a schematic level of representation with the earlier associative network model of emotion. Subjects were required to complete statements about the world that are assumed to reflect dysfunctional models, where the dysfunctional completion word is not one that would be likely to be associated directly with a negative emotion. For example, depressed and control subjects were invited to complete sentences such as "Always to put others' interests before your own is a recipe for --". Depressed subjects tend to respond with a term like "happiness", whereas controls are more likely to produce "disaster" as a completion. This argues against a simple associative model of emotion, which would predict a negative word-completion response from depressed patients, and supports a model based on more complex schemata.

Another approach to teasing out the dysfunctional schemata associated with depression was produced by Barnard, in collaboration with Murray at the Winnicott Unit in a study concerned with the interaction of depressive mothers with their young children. The study analysed the spoken discourse of children playing with dolls in a family situation, using a psycholinguistic technique known as case grammar analysis. The study concentrated on one sub-unit of analysis, animate nouns, which can fulfil a number of case roles including agent, object, experiencer and dative. Children of depressed mothers were consistently less likely to refer to themselves in the agent role than were control children, and more of their self-references were phrased with negative form. Barnard is continuing this work as part of a programme grant to Murray studying the stability of the effect over time and its association with later dysfunction. He also plans to use the method to study depressive adults in different mood states, in particular contrasting the depressive, neutral and manic phases of manic depressive patients. The technique would appear to have considerable promise as an indirect measure of psychological dysfunction.

A major factor in the maintenance of depression appears to be the stream of ruminative negative thoughts that patients often find difficult to break out of. Teasdale has been concerned to understand this process, using both a working memory model, and subsequently ICS. He began by studying the intrusion of irrelevant thoughts in normal subjects observing that they were reduced by a concurrent memory load and appear to be associated with the operation of the central executive, rather than with the visual or verbal slave systems. Consistent with the notion that thought production and tasks making high demands on central executive functions compete for the same limited resources, the occurrence of such thoughts was associated with a reduction in randomness in a random generation task. Equally, the capacity of a task to inhibit them decreased as practice made the task more automatic. This pattern of results links the model with a range of attentional training techniques that have been found to be helpful in teaching patients to cope with pain and stress, and which form part of a study concerned with prevention of relapse in patients treated for depression.

While treatment of depressed patients with appropriate drugs can be very effective, residual symptoms may occur, and when they do so, as many as 78% of patients may relapse within the next nine months. As part of the MRC Neurosciences Approach to Human Health Initiative, Teasdale is collaborating with Paykel in Cambridge and Scott in Newcastle in a clinical trial of depressed patients with residual symptoms. This study compares long- and short-term outcome for patients treated either with drugs or with drugs supplemented by cognitive therapy. Both practical and theoretical aspects will be studied. While there is some evidence to suggest that cognitive therapy leads to a lower relapse rate than antidepressant drugs, it is of course expensive in terms of therapists' time. Teasdale, in collaboration with Williams and with Segal in Toronto, is concerned with attempting to develop and evaluate methods of attentional control which can be taught to the patient relatively easily and subsequently used with a minimum of further supervision. Similar measures are being evaluated by Robertson as a means of helping head injured and stroke patients to manage their attentional and emotional problems more effectively.

Such work on prevention of relapse will continue over the next five years, and will be supplemented by studies based on the ICS model. Teasdale will test the hypothesis that cognitive treatments of depression are essentially concerned with normalising dysfunctional thought patterns, and that to do so requires the patient to develop an alternative store of less depressogenic thought structures. A range of new techniques for measuring such structures and their change are currently under development.

Two new lines of research in this area will result from the appointment of new staff members. Dalgleish will be continuing to study the link between emotional factors and long-term memory, as mentioned above, but will in addition be investigating the effects of emotion on reasoning, beginning with simple syllogism problems which have been shown in normal subjects to be influenced by semantic as well as logical factors. He will begin by exploring whether syllogisms based on factors such as self-worth are particularly vulnerable to distortion in depressed patients. If so this should provide a tool for measuring both dysfunction and recovery, at the same time as giving a method for exploring the nature of the distortion.

Andrew Young who has recently joined the Unit from Durham has worked extensively on the perception and recognition of faces. He has become interested in the question of whether recognition of emotion involves a separate system from that required for processing personal identity. Evidence for such a view comes from the study of an amygdalotomy patient with a specific deficit in the capacity to identify emotional expression. Future work will follow up this and related cases, investigating whether failure to identify emotion from the face will be accompanied by a similar failure to make voice-based emotional judgements. Other studies will be concerned with the suggestion that patients with frontal lobe damage may have difficulty in judgements of facial emotion, and with the development of methods and material for the analysis of emotional judgements in normal subjects. Young suggests that a mismatch between the systems responsible for registering facial identity and facial emotion may be reflected in certain syndromes of delusional misidentification. Patients suffering from the Capgras syndrome believe that those surrounding them have been replaced by impostors, while patients suffering from Cotard delusion believe that they themselves are dead. One hypothesis is that, while recognising the identify of surrounding people, emotional reactions based on the face are distorted, a state of affairs which may induce a suspicious patient to suspect that others have been changed, and a depressed patient to attribute the change to himself. Collaborative work is underway to investigate this hypothesis.

It is clearly the case that facial expression and body posture represent an important channel for communicating socially and emotionally significant information. Research on human-computer interaction using simulated faces and voices has begun to demonstrate the extent to which a person's attitude and behaviour can be influenced by cues that are sufficiently subtle that the subject fails to detect them. One aspect of Barnard's work will be exploring this, and relating it to the work of Young on the perception of emotion by normal subjects and by neuropsychological and neuropsychiatric patients. This area of research is still in its infancy, but has considerable promise for understanding the problems of certain patients in interpreting their social environment, and in transmitting the social signals that, although implicit, are crucial for successful social behaviour.

Role of the APU in the Council's Scientific Strategy

According to the Council's Corporate Plan (p. 72), the Council's Strategy is as follows:

1. To encourage cognitive and developmental psychology, including modelling, to study the development and impairment of perception, memory, cognition and language.

In general, we would regard the area specified as being the heartland of cognitive psychology, and would regard the Unit as continuing to function as a centre of international excellence in the field. Our work is, of course, principally concerned with adult cognition, although it is becoming increasingly clear that work on children can have important implications for general cognitive theories.

2. To develop models of cognitive processes using computational and connectionist approaches that are consistent with clinical and experimental data, and which have a secure theoretical basis.

While computational modelling continues to be a strength in psychophysics (R Patterson) and motor control (Nimmo-Smith, Tresilian, Wing), computational and connectionist approaches to memory are so new that we had difficulty recruiting experienced and trained scientists. Instead we opted for a policy of collaboration (Shallice, Patterson) with existing centres of excellence in the US and developing our own strengths (Norris, Houghton, Shanks). While the Unit has undoubtedly suffered from the move of Shallice, Houghton and Shanks to UCL, we have been able to attract some excellent young scientists to non-established posts (Murre, Page), and to attract some first-rate research students with skills in this area. Our particular strength is in combining theoretical and computational skills with close attention to experimental and neuropsychological evidence. The area is flourishing at the Unit, but in my opinion would benefit from a further senior appointment to ensure its future stability.

3. To expand work on the cognitive rehabilitation of neurological patients building on an understanding of the way the brain functions and on opportunities for relearning.

Our newly developing Rehabilitation research group was set up with precisely this aim in mind. Neuropsychological rehabilitation does not have a strong existing research tradition, either nationally or internationally, but we have been fortunate in attracting two very strong rehabilitation research scientists to form the core of the group.

The turmoil resulting from the re-organisation of the NHS has limited the promised clinical local development in rehabilitation, but fortunately links with colleagues in rehabilitation groups elsewhere have allowed the programme to develop rapidly. A major local bonus has been the recent development of clinical neurosciences within the University, providing a much more hospitable and stimulating clinical environment than the Unit has experienced in the past. The Rehabilitation group has already established an international network of contacts and collaborations, and is receiving far more requests for working visits than can currently be accepted. New accommodation at Addenbrooke's is promised by the autumn, and with the exciting possibility of Wilson's involvement in the development of a model post-acute Rehabilitation Unit, the future looks extremely promising.

4. To develop suitable outcome measures for disorders involving loss of physical, mental and social functions, and use these to inform rehabilitation strategies.

Throughout the whole 50 years of its existence, the Unit has had an interest in using state-of-the-art techniques and concepts from cognitive psychology for the practical purpose of measuring human performance. In the early years, we were principally concerned with the assessment of the influence of environmental stress on military performance, whereas more recently our concerns have been with neuropsychological assessment, and with measuring the impact of emotional factors on cognitive functioning. As predicted in our last Progress Report, our interests are now shifting from assessment to treatment of both emotional and neuropsychological problems. We continue to develop new measurement techniques, publishing them in the standard journals, but are increasingly concerned with the development of standardised tests, for use within a clinical context.

Our clinical work has begun to extend from diagnostic measures to a concern with developing and assessing new treatment methods. In the area of rehabilitation, most of the work is still at the level of single cases or small groups. We are, however, increasingly being asked for advice on larger multi-centre trials, and look forward to the stage at which our new therapeutic techniques are ready for evaluation on this scale. We also anticipate close cooperation with the IRC in Brain Repair, once their work has reached the point at which clinical trials are feasible.

The Cognition and Emotion group have already reached this stage, with their involvement in a multi-centre trial concerned with the influence of pharmacological treatment and cognitive therapy on relapse in depressive patients, a study funded by the Council's Neurosciences Approach to Health programme. Mental health represents an area of enormous importance both in terms of human suffering and economic cost through absenteeism. The Unit is internationally recognised as a centre for excellence for research in this area, as reflected by the involvement of Teasdale in a US-funded project to develop methods of cognitive therapy that are less therapist-intensive.

Finally, there are two areas of the Council's Scientific Strategy in which the Unit is less involved than we would like, namely:

5. To bring together research on animal behaviour, in particular primates, with studies of normal and disordered brain function in humans.

We clearly do not plan to carry out animal work at the APU, but it is already clear from Duncan's continuing collaboration with Desimone at NIH on attention in monkeys, that the concepts and techniques of cognitive psychology are applicable to understanding the data obtained from neurophysiological studies of non-human primates. Duncan would welcome the opportunity of pursuing collaborative work more locally, and has already begun preliminary discussions with Rosalind Ridley whose Council-funded research on primates has recently moved to Cambridge.

6. To apply techniques of in vivo brain imaging to combine studies of cognitive function with anatomical mapping.

Brain imaging combined with good cognitive psychology can be a very powerful tool for investigating the neurobiology and psychology of cognitive function. Patterson and Duncan are already involved in some collaborative work involving PET scanning. However the potential for involvement of the Unit in collaborative work of this kind has hardly been touched, simply because of the lack of access to suitable imaging equipment and expertise. We are therefore delighted to note that such a facility is likely to develop locally in the near future, and expect to play a substantial role in its scientific programme. This does not feature prominently in our current proposals, simply because the development is not sufficiently far advanced for us to be able to present a fully articulated programme. Furthermore, since this would represent a relatively substantial development for the Unit, it is perhaps more appropriate that such detailed proposals should await the appointment of my successor.

The APU and Council Strategy

In writing their introduction, Directors are asked to relate the work of their Unit to the Council's Corporate Plan and Scientific Strategy, and to place it within a national and international context. I have chosen to use the Corporate Plan and Strategy documents as a framework for responding to this request, considering each of the objectives specified and highlighting the way in which the Unit's work contributes, commenting where appropriate on the national and international relevance of our work.

Corporate Plan Objectives

1. To strengthen the research base: We regard our principal role as that of contributing to the continued development of cognitive psychology. We believe that we have maintained the excellent international reputation that was reflected in comments on our last Progress Report, and trust that our peers will support this view on reading the present Progress Report.

2. To address the needs of users, in particular the Health Departments: Over the years, our applications have been progressively more health related, and this process has been accelerated by the development of the Rehabilitation Section. We believe that the attempt to apply cognitive psychology to clinical problems is proving effective in neuropsychology, neurorehabilitation and in our work on cognition and emotion. We believe that our work is innovative, sound and internationally respected. Meanwhile, we continue to interact with a range of other users, including the Home Office, the Ministry of Defence, and industry, where our work on information technology is of particular significance both nationally and internationally.

3. To create a good research environment: We are fortunate in having had the generous and long-term commitment of the Council which has allowed us to create an excellent environment for research in cognitive psychology. Evidence for this is provided by our capacity to recruit first-rate scientists, research scientists and support staff, by the number of visiting scientists who come to work at the Unit (an average of 10 per year) and their subsequent comments.

4. To provide good training and research development: We typically take two MRC students per year and one funded from other sources. Since the Unit began taking students, we have had over 50, of whom only three have failed to complete a PhD. By far the majority have moved on to academic or research posts, with information technology being the next most frequent career.

Even more important than our research student training is the post-doctoral opportunities afforded by the Council's three- to five-year short-term contracts. We are able to attract first-rate candidates, and to offer them the opportunity of broadening their research capability within an active and stimulating research environment, providing a strong foundation for a subsequent academic or research career. Of the 28 holders of short-term scientific posts at the Unit over the last decade, 16 are currently in tenured academic posts, 3 in research posts, 2 in industry and 2 in clinical posts.

5. To work with other research sponsors: While I assume that this is principally aimed at formal Council links, I can report that the APU has been making its contribution by attracting funding from a very wide range of sponsors, ranging from international programmes such as the Human Frontier Program, through European programmes such as Esprit, to more national sources of funding such as the Ministry of Defence, the Home Office and medical charities.

6. To disseminate and apply research: Much of our applied work leads not to a specific product, but rather to increased understanding, which will allow existing activities to be pursued more effectively. Hence our work in information technology depends for its effectiveness on its being conveyed to software engineers, while our

rehabilitation research will only be effective if it is conveyed to therapists. In both these areas we have a high international profile, and intend to continue to devote a substantial proportion of our efforts to ensuring that our work is applied.

More locally, members of the Unit have been involved in teaching in a range of Cambridge departments, including Experimental Psychology, Anatomy, Physiology and Engineering, with occasional courses taught much further afield.

7. International collaboration: The extent of this is obvious from our publication list, which reflects many publications in collaboration with colleagues from a wide range of countries.

8. To increase the public awareness of science: We are fortunate in that psychology is a topic that is of considerable intrinsic interest to the general public. We encourage this growing interest by a consistent willingness to present our work through the media, including television (some 16 programmes and 4 news items over the last five years), radio (12 programmes) and the press, both general (35) and more specialised (47), in addition to Robertson's regular column in the BMJ, and frequent articles in The Times. The press coverage tends to be national, with television being rather more international with the Unit featuring prominently in science programmes made by Dutch, Canadian and Japanese, as well as British companies.

One index of the Unit's commitment to the dissemination of science is the continual stream of requests for information, advice and assistance of varying forms, from the media, from Government, public and private institutions, and from fellow scientists in various disciplines, in this country and around the world. Members of staff are asked to record these outside contacts systematically and a memo, reporting all known contacts is distributed to staff weekly. A summary of these contacts over the last five years is given below.

1989 1990 1991 1992 1993

1. Requests for information/advice: 238 268 216 297 262

2. Invitations to visit: 14 38 18 29 22

3. Requests to visit APU: 49 43 36 57 70

4. Invitations to make a presentation: 178 131 126 226 210

5. Invitations to author/edit books, etc: 23 13 13 25 33

6. Requests for extended commitment of effort: 35 36 41 52 46

Totals 537 529 450 686 643

The reporting of contacts is certainly incomplete, and the above summary statistics therefore merely index the minimum demand on Unit resources. However, meeting even this level of demand represents a considerable expenditure of time and effort by Unit staff, over and above their normal commitments to research and scientific publication. We do, however, regard it as an important and potentially very productive part of our work.

9. To use resources effectively: The previous Visiting Subcommittee, and in particular its foreign members, commented very positively on our efficient use of resources. Over the last five years, we believe that our flexible management structure, making greater use of two assistant directors, has allowed us to be even more cost-effective. A rough indication is provided by the fact that our publication rate has risen by about 14%, with

no increase in number of established posts. A simple publication count does not, of course provide an adequate assessment of quality. For this we rely on our referees.

Concluding Statement

I would like to thank Council for its sustained support for the APU during the fifty years of its life, and for entrusting to me its directorship over the last two decades. I trust that our referees will agree that I am returning it in good heart, ready to begin tackling the challenges and opportunities of the next fifty.

PERCEPTION AND ACTION

Allerhand 4.5, Carlyon 0.5, Goodrich 0.75, McKeown 2.0, Maylor 0.73, Nimmo-Smith 0.75, R Patterson 5.0, Sellen 0.73, Thurston 2.0, Tresilian 2.75, Wilkins 5.0, Wing 5.0, Allison (HSO) 4.0, Chronicle (SO) 0.5, Datta (SO) 1.08, Jeanes (SO) 1.25, McLachlan (SO) 0.25, Milroy (HSO) 1.0

Total Person Years: Scientists 29.7; Research Support 6.3

Abstract

Objectives

This programme employs psychophysical, computational and electrophysiological methods to increase our understanding of human perception and action. The objective is to develop theoretical models for perception and action in normal and impaired performance, and to apply these models to medical and communication problems.

Scientific progress and achievements over the past five years

Progress in the last five years has occurred on three broad fronts: audition, vision and movement control. In audition, a computational model (AIM) has been developed to simulate the auditory images we hear when presented with everyday sounds and to provide a basis for source identification. Applied work has led to the provision of auditory warnings in a variety of high-workload environments. In vision, an electroencephalographic investigation of photosensitive epilepsy has led to a general, unified theory of visual stress. The theory encompasses photophobia in migraine and perceptual distortions in dyslexia. It has been applied to recent developments in lighting and visual displays. In movement control, models of the variability of elemental aspects of movement (force and time) and of visual control of action have been proposed and tested. Various tasks, including reaching, grasping and standing, have been investigated to develop our understanding of co-ordination.

Specific scientific achievements

The primary achievements in audition are (a) a set of experiments to demonstrate the role of neural, time-interval patterns in the perception of sound quality, and (b) the development of a computational model of hearing with a strobed temporal integration mechanism to convert repeating time-interval patterns into stabilised auditory images. The success of the resulting Auditory Image Model, AIM, has led to the development of a software package that simulates the activity patterns produced by sounds at various levels in the auditory system. A wide range of investigators are testing the package as a front-end for speech

recognition systems, and as an explanatory tool for the role of time-interval information in the perception of sound quality. Research on auditory warnings has culminated in the production of a warning system for British Rail and the publication of European and International standards on hospital warnings.

In vision, a new system for precision ophthalmic tinting (the Intuitive Colorimeter System) has been developed from conception and patenting through to marketing, and it is now moving into general optometric practice. Preliminary clinical observations, an open trial, and a double-blind, placebo controlled, cross-over study have consistently demonstrated benefits in reducing eye¬strain and headaches.

The research in movement control has supported models of force and timing when subjects are explicitly required to control these aspects of movement. Empirical support has been obtained for a variety of visual cues contributing to interception skills. Under the heading of co-ordination it has been shown that grip force, used to stabilise an object in the hand, is modulated in anticipation of loads induced by arm kinematics. Finally, methods for investigating whole body stability have been developed.

Future plans for the next five years

In audition, the proposals for future research focus on the neural time-interval information produced by a sound and how the auditory system uses this and other information to separate signals from background noise in everyday life. The research will concentrate on two synthetic sounds which produce complex tone and noise perceptions that traditional auditory models fail to explain. The stimuli are matched pairs of damped and ramped sounds and iterated rippled noise. The perceptions are interpreted in terms of the time-interval patterns the sounds produce in the auditory image. The recent appointment of a second auditory scientist will enable us to expand our auditory research to source segregation. Although we experience sounds as separate sources, their acoustic waves are completely intermixed when they arrive at the ear; proposed research in this area will focus on how the individual sources are recovered by the listener.

The theory of visual stress suggests that precision tinting will also have therapeutic benefits in photosensitive epilepsy and migraine; the proposals for future work thus involve evaluating ophthalmic tinting in these disorders. The study of the mechanisms that underlie the beneficial effects will continue, with an emphasis on objective correlates of the subjective effects.

Proposals for future work on movement include evaluation of the control of force, timing and position in bimanual tasks with a view to synthesising a model of movement control from elemental component processes. Formal models for between-hand co-ordination within individuals will benefit from analyses of between individual co-ordination in rowing. Analyses of anticipatory processes involved in minimising the destabilising effects of voluntary movement will link studies of grasp and standing balance. The work will include studies of impaired function in the elderly and in neurological disorders of movement.

Implications for improving health, health care, and wealth creation

During the current reporting period, work in this programme has resulted in 6 patents, three of which have produced licence fees. In most cases, there is an industrial collaboration associated with the patent which increases the potential for wealth creation and widens the circle of dissemination of the underlying science. All of the patents have applications in healthcare.

In audition, it is anticipated that the auditory image model will be incorporated into a preprocessor for automatic speech recognition and eventually machine translation. The AIM software is distributed electronically to facilitate technology transfer and the dissemination of the science. The research on sound separation should lead to improvements in the operation of recognisers and hearing aids operating in noisy environments. Implementation of the new hospital warning standards should now begin to reduce preventable accidents in operating theatres and intensive care units.

In vision, further clinical trials of precision ophthalmic tinting may lead to an inexpensive treatment for light-sensitivity in migraine, a common component of a disabling disorder. The development of filters for use in the classroom may help to prevent reading difficulties in children. A search for objective correlates of visual discomfort may improve methods of assessment.

In movement control, investigations of standing balance have resulted in a patent that has lead to a commercial product, Swayweigh. This device will be useful to clinicians, therapists and patients in the diagnosis and remediation of balance problems including those resulting from stroke. Future research on balance after stroke and other neurological motor disorders should enable the development of fruitful new physical therapy approaches to rehabilitation. Research on two-hand co-ordination will suggest possible new dimensions for interaction with computers.

THE AUDITORY IMAGE (Allerhand, McKeown, R Patterson)

Introduction: Auditory Images and the Space of Auditory Perception

When an event occurs in the world around us, we experience an auditory image of the event, in the same way that we experience a visual image of the event. The auditory image reveals the pitch and loudness of the source and its sound quality, or timbre. These properties enable us to identify voices and musical instruments, and they tell us whether a speaker is angry or sad and whether a note is mellow or harsh. We have developed a theory of auditory image formation and a computational model to express the theory in concrete form. The theory distinguishes between the construction of auditory images by the peripheral auditory system and the processing of the images by the central auditory system. These are the two basic research themes in the report for this area. There are also two applied research themes: the application of auditory image theory to speech processing, and the design of auditory warning sounds. The report begins with a brief introduction to the concept of auditory images and the representation provided by the Auditory Image Model (AIM).
Auditory images are constructed in three stages, each of which creates a dimension of the space of auditory perception (Figure 1). The first two stages simulate the frequency analysis performed in the cochlea and the laterality analysis performed in

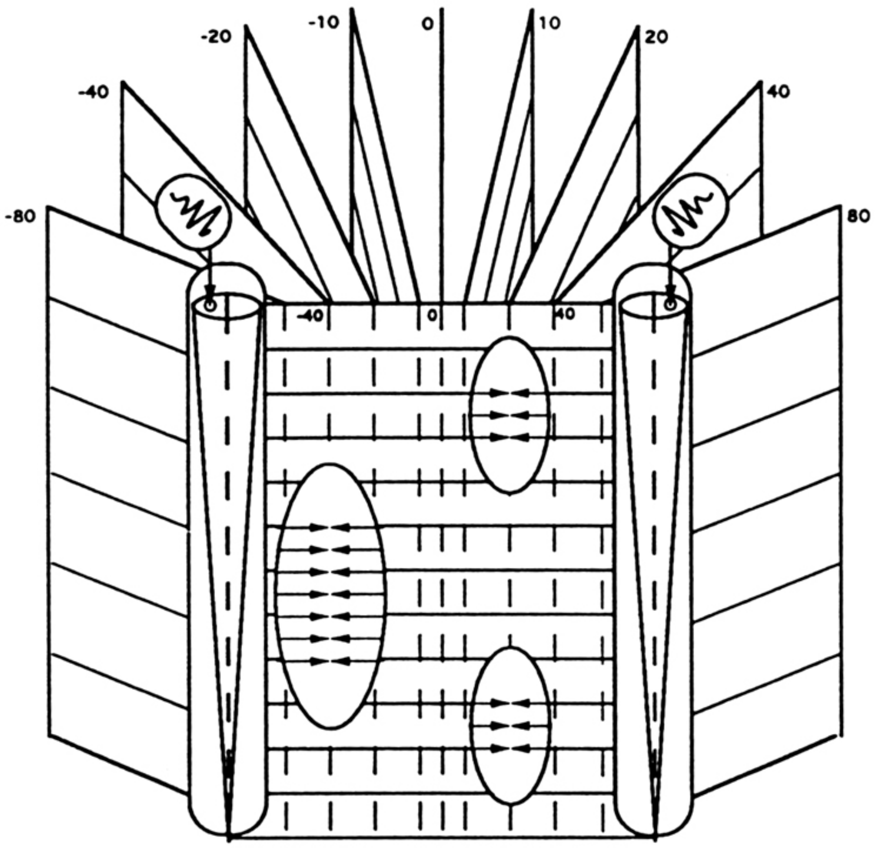


Figure 1. The space of auditory perception in the auditory image model.

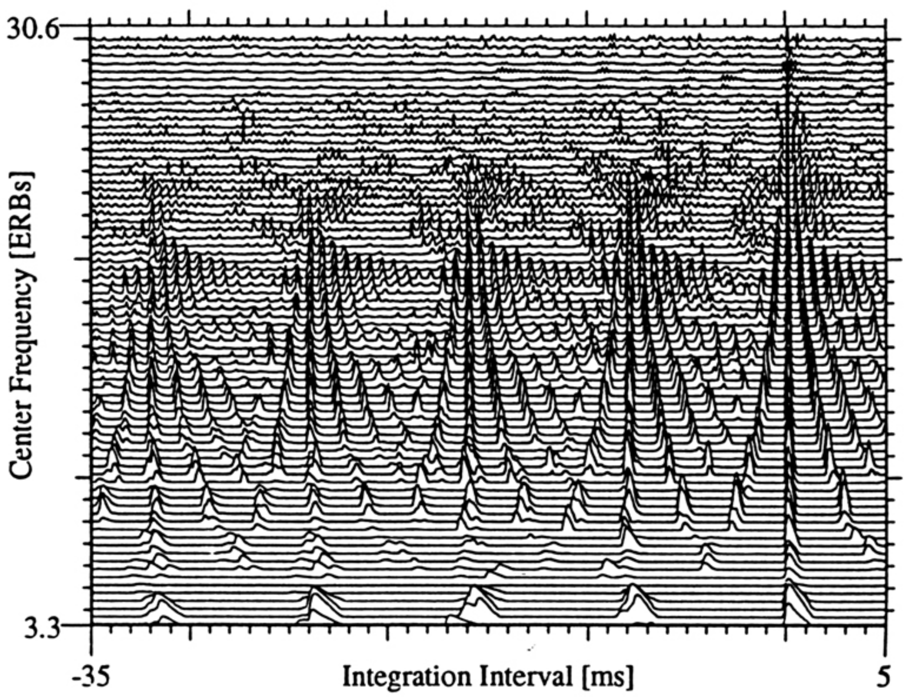


Figure 2. The auditory image of the vowel /ae/, as in 'hat'.

the midbrain. Frequency and laterality are the vertical and horizontal dimensions of the plane in the centre of Figure 1. The activity generated by a compact sound source appears on a vertical line in this representation. The figure illustrates the separation of two sources, one 40 degrees to the right of the listener and containing energy in the mid-frequencies, the other 20 degrees to the left with energy at higher and lower frequencies.
In previous auditory models, this lateralised spectral analysis was assumed to represent peripheral auditory processing in its entirety, and all information concerning sound quality was assumed to be coded in the spectrum by relative intensity. The distinctive sound qualities we hear in music and speech, however, indicate that auditory image construction includes a sophisticated temporal integration mechanism and an analysis of the time intervals in the resulting neural activity pattern. It is as if the system maintained a large array of post-stimulus-time histograms behind the frequency-laterality plane, one for each frequency-laterality combination. Integration into the histogram is triggered by local maxima in the neural activity; the set of histograms activated by a point source form a vertical plane like those shown in Figure 1 behind the frequency-laterality plane. The structure that forms in the plane is the auditory image of the sound. When it is tonal, the histograms are regular and related as in the low-frequency channels of Figure 2 which shows a vowel presented in noise. When the sound is noisy, the plane contains irregular and unrelated histograms as in the upper channels of Figure 2 where the noise dominates.
In summary, auditory image theory suggests that peripheral auditory processing creates our space of auditory perception and our initial images of sounds. The auditory image represents our initial experience of the sound and is the basis of all subsequent auditory processing. Specifically, the theory provides a framework for understanding how the auditory system analyses acoustic events and how it characterises sources.

A. Auditory Image Construction

Patterson, Allerhand, Holdsworth, Akeroyd, Datta, Manson, Irino)

A1. Implementation:

The Defence Research Agency (Farnborough) awarded APU a grant to develop a reliable computational version of AIM, to tune it to calibration sounds, and to test its ability to measure stress in speech.

A1.1 AIM software development:

State-of-the-art software engineering principles were used to design a sophisticated platform and a user-friendly interface for AIM . This included (a) multiplex processing so that AIM can be applied to sounds of indefinite length, (b) an extensive display system that provides dynamic spectra and spectrograms as well as auditory images, (c) a source-code management system (SCCS) to facilitate maintenance of what is now more than 30,000 lines of code, (d) control programs to compile and build the model automatically, (e) routines to mail the package to collaborators electronically, and (f) routines to unpack and rebuild the package on a range of machines. In June 1991, AIM Release 5.0 was made available to collaborators (1.109).

A1.2 Tuning, testing and dissemination:

The model was tuned with click trains to set the temporal integration parameters, and with co-modulated tones to set the adaptation and suppression parameters (1.66). The system was tested with musical notes and diphthongs to show that the images of tonal sounds expand and contract horizontally as the pitch of the sound changes and the formants move up and down with changes in vowel quality. AIM was applied to pairs of concurrent vowels to illustrate how a pitch difference aids vowel separation in a time-interval model. It was also used to explain the sequence of perceptions that arise as the spectral density of a set of inharmonic sinusoids increases from one to five hundred (Profile Analysis). The adaptive thresholding mechanism and the image stabilisation mechanism were patented (1.119, 1.120). Invited papers were presented at conferences of physiologists (1.65), psychoacousticians (1.66), and speech scientists (1.85) to facilitate rapid dissemination of this new approach to hearing.

A2. Research:

The auditory images of everyday sounds reveal short-term temporal asymmetries; the formants of the vowel in Figure 2 are examples. Traditional auditory models treat these short-term asymmetries as phase changes which are removed entirely, or blurred, in the course of temporal integration. AIM preserves short-term asymmetries (1.79), and we believe they play an important role in the auditory analysis of sound quality. This led us to focus our research on a new class of sounds produced by applying asymmetric temporal modulation to continuous sounds. The strategy was to construct sounds with identical energy spectra that produced different auditory images and show that people hear differences in the sounds analogous to the differences in the images.

We used an exponential damping function as the modulator and reset the amplitude to its starting value every 25 ms to produce a sustained "damped" sound. The time-reversed version of this stimulus is referred to as a "ramped" sound. The continuous sound, or carrier, was either a sinusoid or a broadband noise, both of which have highly distinctive sound qualities. The damped and ramped versions produce major differences in what is heard, indicating (i) that temporal asymmetry is preserved in the auditory image even over short intervals, and (ii) that purely spectral models of hearing will have great difficulty explaining the timbre of everyday sounds.

A2.1 Damped / ramped tones:

Our first study revealed that the internal representations of damped and ramped sounds differ because the impulse response of the auditory filter is asymmetric and it interacts with the asymmetric envelopes of damped and ramped tones. The damped sound produces activity in a narrower range of auditory filters than the ramped sound, but listeners report that it is the ramped sound which has the stronger sinusoidal quality (1.18). The perceptual difference between damped and ramped sounds exists for a wide range of carrier frequencies and repetition rates. In these regions, the auditory image contains more time intervals at the period of the sinusoidal carrier for the ramped than the damped sound (1.19). It was concluded that it is time intervals at the appropriate period rather than a spectral peak at a specific frequency that determines whether a source will have a sinusoidal sound quality.

A2.2 Damped / ramped noise:

A wideband noise with a repeating ramped envelope sounds like a repeating noise; when the envelope is reversed, the resulting damped noise sounds like a shallow drum being struck with brushes! As with damped/ramped tones, the difference between damped and ramped noises exists for a wide range of stimulus conditions (1.63). In this case, however, the asymmetry does not arise in the cochlea. We have developed two mechanisms to explain the dramatic perceptual differences that we hear in damped and ramped noise. Both are based on the derivative of the envelope of the neural activity flowing from the cochlea; but whereas one is applied before temporal integration (1.82, 1.101), the other is applied during temporal integration. Experiments to determine which is the more appropriate site for the asymmetry are included in our future proposals.

In summary, these two new timbre discriminations demonstrate the importance of preserving short-term temporal asymmetry in our internal representations of sounds, and further that asymmetry arises both in the cochlea and at more central levels in the auditory system.

B. Auditory Image Processing

(Patterson, Allerhand, McKeown, Robinson, Akeroyd, Datta)

In the current reporting period, image processing was limited to research with a spiral representation of the auditory image (1.120).

B1. Octave Perception and the Spiral Auditory Image:

We performed two studies on octave perception, demonstrating (a) that many musical notes have non-integer octave ratings when compared with those of equivalent sinusoids (1.17), and (b) that the spiral form of the auditory image can explain the non-integer octave ratings (1.86). The studies also indicated that the auditory image is probably stabilised in the process of construction before, rather than after, pitch extraction. This hypothesis was supported by two series of experiments, one with short- duration musical notes which showed that the timbre of a note can be categorised more accurately than its octave or chroma (1.53, 1.54, 1.113,), and the other with short concurrent vowels which showed that the timbre of the dominant vowel is available from single cycle stimuli (1.52). As a result, work on image stabilisation displaced work on spiral image processing for the time being.

B2. Pattern Recognition and Speech Stress:

Following development of a computational form of strobed temporal integration, a pattern recognition mechanism was developed for the stabilised spiral output of AIM (1.64, 1.97, 1.98). It learns the forms of regularity that occur in a given data base and, once trained, can be used to identify the stressed syllables in continuous speech (1.78) or the degree of vocal agitation in the speech of pilots operating under emotional stress (1.94).

C. Application of AIM to Speech Sounds

(Patterson, Allerhand, Holdsworth, McKeown)

(Collaborators: Cutler, Norris, Fallside, Almeida, Schwartz, Hirahara, Anderson)

Speech recognition machines with traditional spectrographic preprocessors perform poorly in noisy environments, whereas human speech recognition is highly noise resistant. This led us to propose AIM as a preprocessor for speech recognition machines which, in turn, led to a series of collaborations in speech research.

C1. Auditory/Connectionist Techniques for Speech (ACTS):

The European Commission (ESPRIT BR) provided a grant to develop and test an auditory/ connectionist speech recogniser.

The data-rate problem: Traditional recognition systems use spectrographic representations of speech with data rates around 2 KiloBytes/second. The auditory image representation has an extra dimension and, as a result, its data rate is around 2 MegaBytes/second. Consequently, two modules were added to the AIM package so that the output of both the cochlea simulation and the auditory image could be time-averaged and down-sampled into a spectrographic form. This enabled us to interface AIM to (i) a Time Delay Neural-Net recogniser developed at APU, (ii) a Kohonen Net recogniser developed at INESC in Lisbon, and (iii) a recurrent error-propagation network developed in the Cambridge University Engineering Department (CUED) (1.85).

AIM and phoneme recognition: The most comprehensive recognition study was performed with the CUED recogniser; it involved training and testing the system with the complete TIMIT database (over 7000 sentences). It showed that phoneme recognition performance with an auditory/connectionist system was comparable to that from the best HMM recogniser available at the time (1.87). The other AIM/connectionist systems yielded similar results on smaller data sets. They are described in the annual project reports (1.110, 1.111, 1.112), along with about 20 papers on the development of the recognisers and their motivation.

C2. AIM as a Preprocessor for Speech:

In collaboration with the largest Japanese speech group at ATR in Kyoto, we developed an auditory/HMM phoneme recogniser (Patterson & Hirahara, 1989) that used a spectrographic reduction of the auditory image. It performed somewhat better than a traditional system when the size of the recogniser was constrained and the speech was noisy. The differences were significant but they were not large.

In collaboration with Armstrong Laboratories at Wright-Patterson Air Force Base in Ohio, we have set up an auditory/Kohonen-net recogniser to process Timit data. The system uses a spectrographic reduction of the neural activity pattern from AIM. It has so far demonstrated small but significant advantages over traditional recognisers in phoneme recognition (1.80) and speaker identification (1.84). Together, all of these studies make two important points:

(1) Auditory models are just as good as traditional preprocessors employed in speech recognition, even when the temporal fine-structure is removed to reduce the data rate, and even though they were not specifically tuned for speech sounds (1.85).

(2) To achieve the performance demostrated by human listeners, speech features will have to be extracted from a representation like the auditory image which contains fine-grained temporal information.

D. Auditory Warnings *(Patterson, Datta, Milroy) (Collaborator: Lower)*

Over the past decade, at the request of several government agencies (CAA, MOD, DTI, BR, BSI), we developed sets of auditory warning sounds to alert operators to life threatening situations in hospitals, aircraft and trains. A combination of auditory theory and ergonomics was employed to ensure that the warnings were, at one and the same time, more distinctive (therefore more memorable) and less startling (therefore less irritating) than existing commercial warnings. During the current reporting period, commercial systems were installed in civil helicopters flying to North Sea oil rigs and military helicopters sent to the Gulf war. The design principles were published with illustrations of their application in aircraft and hospitals (1.16, 1.89).

D1. Track-side Warnings:

Following our development of a system to alert track-side maintenance staff to approaching trains, British Rail Research requested that APU support the commercial development of the production version. Field measurements made at a test installation track beside the main line showed that some forms of the device did not meet the specified sound levels because the speaker was jammed in the housing (1.102, 1.105). Headsets were reviewed for use in extreme noise backgrounds (1.104), and finally, a procurement specification and quality control procedure were written (1.103). This work is now complete.

D2. Civil Aircraft Warnings:

Following two airline disasters, the CAA asked us to design a warning to aid passengers evacuating a smoke-filled aircraft. Tests with warnings mounted near exits demonstrated that they were readily localisable (1.106), and an evacuation test in a BAC 111 showed that the system did improve the speed of evacuation from the smoke-filled fuselage. This work is now complete.

D3. Hospital Warnings:

We provided support to DTI during the development of hospital warning standards by the BSI in the UK, by CEN in Europe, and by the ISO internationally. Recently, these draft standards received majority votes, and so they will become mandatory standards in the near future.

D4. Military Aircraft Warnings:

Recently, DRA requested that APU support a multi-national effort to develop localisable auditory warnings to tell the pilot whether there is an aircraft problem or an external threat. Our initial task was to extend the frequency range of the existing helicopter warnings to 12 kHz without changing their character. Three methods were developed for extending the frequency range; each method proved successful with at least some of the existing sounds (1.108). This is a continuing project as described in section D4.

FUTURE RESEARCH AND TECHNOLOGY TRANSFER

A. Auditory Image Construction *(Patterson, Carlyon, Allerhand, Akeroyd, Datta, Irino)*

(Collaborators: Giguerre)

A1. Implementation:

Two recent developments lead us to believe that is time to produce a professional version of AIM, both as a means of disseminating our basic research and as a means of facilitating the transfer of AIM technology to industry. The first development involves an American programme to demonstrate the value of analogue VLSI chips through development of a 'silicon retina' and a 'silicon cochlea'. Through our collaboration at Armstrong Laboratories, AIM has been chosen as the model for the 'silicon cochlea'. If successful, the chip will greatly accelerate the use of auditory models in hearing, speech and music research. The chip is also intended to support commercial development of verbal computer interfaces. The second development occurred at APU. In August 1993, we began regular distribution of AIM to our collaborators by anonymous ftp. APU records the traffic into ftp accounts; to our surprise, we found that 125 sites acquired the full AIM package in the eight months following its installation. Although we do not imagine that all 125 investigators are using AIM regularly, this take-up rate does indicate that there is demand for an auditory modelling package. This section presents our proposals for a professional release of AIM.

A1.1 A physiological cochlea for AIM:

A state-of-the-art, physiological cochlea simulation has been developed in the Cambridge University Engineering Department. They used the AIM software platform and replaced our linear, feed-forward cochlea with a non-linear, active-feedback cochlea. The physiological cochlea can simulate auditory distortion products and cochlear echoes and, as a result, it can be used to support research on hearing loss at the cochlear level. With financial assistance from the Cambridge Psychology Department, we are installing the physiological cochlea in parallel with our functional cochlea in the AIM software package. We propose to create demonstrations to illustrate the conditions under which one or the other of the cochlea simulations is preferred. The physiological cochlea will enable us to collaborate on the modelling of hearing disorders with the hearing group in the Psychology Department.

A1.2 A correlogram module for AIM:

There are several auditory models that stabilise time-interval patterns from the cochlea using multi-channel autocorrelation rather than strobed temporal integration. The resulting correlograms are similar to auditory images but more symmetric. We have derived the underlying mathematical relationship between the correlogram and auditory image models (1.79). We have written a correlogram module that is compatible with the AIM software, and we propose to integrate it into the package to enable direct comparison of the correlograms with auditory images as representations of what we hear. When completed, the AIM package will be able to simulate most of the models currently used for auditory perception -- including traditional spectral models.

A1.3 An X-Windows interface for AIM:

The current command-line interface to AIM provides fast, flexible control of the model. Nevertheless, it requires some learning on the part of the user. Software engineering research indicates that an X-Windows, menu-driven interface is essential if AIM is to gain user acceptance beyond the Unix-programmer community. There are now excellent tools available for building X-Windows interfaces, and a pilot project to provide such an interface for our image review system was highly successful. We also propose to develop support facilities for AIM in the form of on-line documentation, demonstration scripts, a library of example sounds, and a package of tools to facilitate auditory image processing. The on-line manual will be compatible with the widely used UNIX man system.

A1.4 Auditory image video facilities:

Using relatively crude techniques, we have made videos of the auditory images produced by dynamic sounds and found that they are an invaluable tool for explaining the auditory image concept. The videos lead us to believe that real-time auditory-image displays will also prove valuable for remedial speech training with children and as teaching aids for musicians. Indeed, a plug-in peripheral for televisions, with a silicon cochlea and real-time image stabilisation, would enable one to watch auditory images of music and speech while listening to the sound. While this may seem a frivolous illustration, it is worth noting that it is the entertainment market that originally brought down the cost of video machines. In any event, we believe that auditory image videos will play an important role in expanding the use of auditory models and the public understanding of science. To facilitate this development, we propose to purchase a video system that will play auditory-image bitmaps to a video recorder at the appropriate rate. Previous methods of producing videos have resulted in low-resolution, jerky images produced with great labour.

A2. Research:

The perception of damped and ramped sounds will be used to refine the mechanisms used in the construction of auditory images.

A2.1 Damped / ramped tones:

A ramped tone generates carrier activity across a wider range of frequencies than a damped tone, and the size of the difference observed in the auditory image is affected by the degree of compression in preceding stages. In the functional version of AIM, the compression function is logarithmic; in the physiological version, it is linear at low and high levels and compressive at moderate levels. We propose to perform two sets of experiments to determine the appropriate form of the compression function for a perceptual model of hearing.

Matching the sinusoidal component of damped and ramped tones: As previously (see 1.18, 1.19), listeners will be presented a ramped and a damped tone in random order and asked to choose the one with the stronger sinusoidal component. The half-lives will be varied to identify the region in which this is a difficult decision. It is assumed that these matched pairs generate roughly the same number of carrier periods in the biolgical auditory image, and so we will adjust the compression in AIM to achieve a carrier-period match in the simulated auditory image. The experiment will be replicated at different intensity levels, since the physiological cochlea simulation is level dependent.

Masking by pairs of damped and ramped tones: The shape of the auditory filter can be measured by positioning two masking tones near a narrow band of noise and measuring threshold for the noise signal as a function of the frequency difference between the masking tones. We propose to employ this technique (a) with a damped noise and damped tonal maskers and (b) with a ramped noise with ramped tonal maskers. If the perceptual difference between damped and ramped tones arises in the cochlea as hypothesised by Patterson (1.18), the filter shape derived with the ramped stimuli will be wider than that derived with the damped stimuli. Again, the size of the difference depends on the degree of compression, and the AIM compression value will be adjusted in accordance with difference between the two filter shapes.

A2.2 Damped / ramped noise:

Enhancement of a frozen segment of noise in a jittered damped noise. The strobed temporal integration mechanism in AIM has the unique property of increasing the signal-to-noise ratio of sound components that occur a fixed interval from a strobe pulse repeatedly. We will attempt to demonstrate that such components are enhanced in the auditory system. A jittered damped envelope will be constructed in which the envelope peaks occur every 30 ms, on average, but with individual temporal displacements of 0, 5 or 10 ms in either direction. The envelope will be applied to a random noise into which a 5-ms segment of frozen noise will be inserted every 30 ms, on average. In one case, the spacing between occurrences of the frozen segment will be fixed at 30 ms, independent of the position of the envelope peak; in the other case, the frozen segment will be shifted to be a fixed interval from the envelope peak. We will measure the detectability of the frozen noise segment as a function of its position relative to the peak. In AIM, the envelope peaks will drive the strobe units and so we would expect to find that the frozen noise is more detectable when it occurs a fixed interval from the envelope peak.

A2.3 The spectral spread of strobe pulses:

In AIM, the strobe units that initiate temporal integration operate independently; that is, they search for local maxima only in their own channel. Our auditory images of periodic sounds are extremely stable, which suggests that a large local maximum in one channel may entrain strobe units in nearby channels with relatively weak local maxima. We propose to perform a masking release experiment to determine whether there is cross-channel strobe interaction. A stream of tone pips will be presented in noise and adjusted to be near threshold. The mean interval between tone pips will be 30 ms but the precise position will be shifted a random amount up to 10 ms in either direction. We will then introduce streams of clicks in channels above and below the tone-pip channel; the mean inter-click interval will be 30 ms. In one condition the clicks will be synchronised to the tone pips; in other conditions the click stream will be either random or perfectly regular. If threshold is lowest when the clicks are synchronised to the tone pips in the synchronised click condition, it will indicate that synchronised strobe activity in a range of channels entrains strobe units in adjoining regions when the strobe stimulus in that region is weak.

B. Auditory Image Processing *(Patterson, Carlyon, Allerhand, Akeroyd, Datta, Handel)* *(Collaborators: Yost, Fay, Feth)*

B1. Octave Perception and the Spiral Auditory Image: The spiral representation of octaves will be required to explain the form of musical scales, and it offers a solution to the problem of octave errors in speech recognition. Currently, however, it is not a priority.

B2. Pattern Recognition and Sound Quality Discrimination:

The auditory image measures developed at APU (pitch strength and loudness (1.78)), and the correlogram measures developed at Loughborough (concurrent vowel heuristic) will be developed into a set of metrics for sound quality discrimination. The purpose is twofold: 1) to establish a metric for the degree to which a given auditory model can explain existing discrimination data concerning pitch, damped and ramped sounds and concurrent vowels, and 2) to develop a comparison metric for evaluating different auditory models (e.g. AIM and the correlogram model). Together these metrics will also enable us to determine when a proposed improvement, like the transmission line filterbank or the Meddis transduction module, makes a quantitative difference to our ability to explain discrimination data.

B3. Time-Interval Patterns and Sound Quality:

At the start of his famous book, Helmholtz (1885) states that the most prominent distinction in auditory perception is that between tones and noises, and that the first job of auditory scientists is to explain this distinction. Broadly speaking, tones are produced by periodic sounds and noises by aperiodic sounds; but little is known about just how regular a wave must be for us to hear a tone, or how irregular a wave must be for us to hear the characteristic shshsh of noise. A pair of damped and ramped noises with the same half-life have the same degree of irregularity in physical terms, but one produces a shshsh perception and the other does not. Our work with auditory images suggests that the distinction between tonal and noisy perceptions is determined by the degree of regularity in restricted regions of the auditory image as opposed to regularity in the acoustic wave per se, and that this distinction sets up a figure/ground relationship in the auditory image. In the next reporting period, we propose to investigate these hypotheses and attempt to model them in terms of regularity in the auditory image.

B3.1 The perception of iterated rippled noise (IRN):

Rippled noise is constructed from a random noise by delaying a copy of the random noise and adding it back to the original. The delay-and-add process introduces ripples into the spectrum, with peaks at multiples of the reciprocal of the delay and valleys midway between them. Rippled noise sounds like a pair of concurrent sources, a weak tone with a prominent broadband noise. When the delay-and-add process is repeated, or iterated, the tonal component of the perception grows stronger and the noise component grows weaker; by about 10 iterations, the noise component of IRN is barely noticeable. When the delay is long (say 16 ms), the spectral peaks are closely packed (every 62.5 Hz) and, in the region above about ten times the peak spacing, the auditory spectrum of the IRN is quite similar to that of random noise. Thus, a spectral model of hearing would suggest that, if random and iterated noises are highpass filtered and equated for energy, they should not be discriminable. Nevertheless, they are perfectly discriminable; one has the shshsh of noise and the other sounds like a buzzy musical note.

The timbre contrast between random and iterated noises led us to suspect that IRN would be more detectable in random noise than in IRN, and that random noise would be more detectable in iterated noise than in random noise. A short experiment was performed with an IRN having 256 iterations. When the masker was a random noise, the IRN signal was 4 dB easier to detect than a random noise signal; when the masker was an IRN, the IRN signal became 6 dB harder to detect while the random noise became 14 dB easier to detect. Thus, the availability of a sound-quality cue based on temporal regularity leads to a 20-dB interaction in masking threshold where a spectral model would predict no difference whatsoever! We propose to measure the interaction as a function of the position of the highpass filter. If the pitch is based on spectral peaks, then performance will improve as the delay decreases. If the discrimination is based on fine-grained time-interval information, then the interaction should decrease as the highpass cutoff increases, since auditory phase locking decreases at high frequencies.

B3.2 Auditory figure / ground:

The auditory images of tonal sounds are static, complex, 3-D figures with regular interiors (Figure 2); the auditory images of noises are scintillating, featureless, irregular fields. When they occur together, there is a strong figure/ground separation between the components of the image dominated by the tonal sound vs the noise. We believe that figure/ground separation is probably the first stage of image processing in the auditory system and that it is based on temporal regularity in the auditory image. We propose to develop measures of regularity based on the auditory images of IRN; there are both regular and irregular regions in the images of IRN and the size of the regular region grows with the number of iterations. We will begin with measures that locate concentrations of regularity in individual channels and peak alignment across channels. In this way we hope to develop a method of isolating auditory figures in images and separating them from the irregular regions associated with background noise.

C. Application of AIM to Speech Sounds *(Patterson, Allerhand, Datta) (Collaborators: Anderson, Kawahara)*

C1. Auditory/Connectionist Techniques for Speech (ACTS):

The Esprit BR project imposed an excessive burden of administration on the auditory group at APU. This drew us away from our core research, and so when the Esprit project ended, we withdrew from the management of large speech projects.

C2. AIM as a Speech Preprocessor:

Our speech recognition work will continue through our international collaborations. The collaboration with Armstrong Laboratories on phoneme recognition will be extended to word recognition, where we will attempt to show that an AIM/HMM system supports word recognition to the same level as systems with traditional preprocessors. We are also planning to develop a binaural version of AIM at Armstrong Labs with the assistance of Bochem University in Germany. The purpose of this system is to segregate a speech source from diffuse background noise binaurally before reducing the neural activity pattern to a spectrographic form. This system has the potential to show a dramatic improvement for speech recognition in noise. It is also through Armstrong Labs that we collaborate on the 'silicon cochlea' programme.

The collaboration with ATR in Kyoto will continue through our participation in a programme to develop a biological framework for speech perception and perception. Our contribution involves research on source separation through auditory figure definition.

C3. Speech Cleaning with AIM:

There is a new algorithm for resynthesising sound from correlograms and auditory images. This suggests that it may one day be feasible to 'clean' speech for recognition systems, hearing aids and communication systems by (a) isolating the voiced parts of speech in auditory images on the basis of their internal regularity, (b) separating the voiced parts of the speech from background noise through their figure/ground relationship, (c) resynthesising the voiced speech, and (d) recombining it with a reduced background component. We will look for an opportunity to assemble a software prototype of such a cleaning system in collaboration with one of the resynthesis groups.

D. Auditory Warnings from AIM (Patterson, Datta)

D4. Military Aircraft Warnings:

DRA has a requirement for new warning sounds to signal threats to an aircraft from the ground or the air. The individual threat warnings should be separately identifiable. At the same time, they should also have a distinctive general form to indicate that they are threat warnings rather than flight-systems warnings. We propose to use damped and ramped sounds with complex carriers as building blocks for the new warning sounds, and to use AIM to as the design platform. Individual cycles of damped and ramped sounds will be assembled into groups with distinctive, partially random, inter-pulse intervals to add a degree of sharpness and buzz to the sounds. Then the groups will be combined with partially random inter-group intervals to give sounds with a roughness and sharpness that make them urgent in a way that has not been heard before.

CONCURRENT SOUND SEGREGATION *(Carlyon)*

Introduction

This part of the report describes the research of Dr. R. Carlyon, who joined the Unit in April 1994. The discussion of his previous work is provided as a background to his proposals for future research.

Background

The task of listening to one sound, such as a voice, in the presence of a competing sound, such as a second voice, is one of the most demanding faced by the auditory system. Not only does the composite waveform of the two sources have to be analysed into its constituent frequency components, and the changes in those components tracked over time, but the system also has to determine which components belong to which source. This problem is exacerbated by the fact that, in the case of speech, the two voices will usually have frequency spectra which overlap, and will share similar temporal characteristics. Much of Carlyon's research has investigated how we compare information in different frequency regions in order to separate concurrent sounds perceptually. Typical tasks have required the listener to detect differences in fundamental frequency (F0, the physical analogue of pitch) between two groups of frequency components, or to try to detect differences in the pattern of frequency modulation (FM) imposed on two individual components. Because many of his recent findings form the impetus for future experiments, they will be described in later sections. However, it is worth making two general points regarding those experiments. First, they used forced-choice tasks, requiring listeners to discriminate between a stimulus that would normally correspond to a single source, and one which would normally arise from two sources. This method has several advantages over other procedures, such as those requiring listeners to rate stimuli according to their degree of "perceptual fusion": one advantage is that it allows a rigorous, quantitative test of different auditory models, for example by the application of signal detection theory. Second, care was taken to ensure that listeners were definitely performing across-frequency comparisons: the components to be compared were always well-separated in frequency, and any within-channel interactions were masked by noise. Across-frequency comparisons are useful when there are regions of the combined spectrum of two sounds which contain energy from only one source, and where the listener needs to assign those regions to the appropriate sound -- for example, where the formants of two vowels from different speakers are interleaved across the frequency spectrum.

Several of the new experiments proposed are motivated by the fact that, in many situations, formants are not simply interleaved: instead, there are frequency regions which contain energy from both sources. Therefore, in addition to extending Carlyon's earlier work on across-frequency processing, we will investigate the within-channel cues that listeners use to segregate concurrent sounds. In this case, however, it is not appropriate to require listeners to discriminate between a sound consisting of two sources (e.g., two F0s), and one consisting of a single source. This is because some within-channel cues, such as beats, can be detected using a minimum of processing, without necessarily being useful for concurrent sound segregation. The experiments on within-channel cues will therefore require listeners to segregate two components, or groups of components, that are very close in frequency, and then to compare one of these to a third sound, which is separated from the other two in either frequency or time.

FUTURE PROPOSALS

A. Extracting Two Periodicities in the Same Frequency Region (*Carlyon*)

A1. Background and Pilot Experiments.

One way of segregating two sounds that occupy the same frequency region is by differences in their F0s. Although listeners can exploit the cue using only across-channel mechanisms (Carlyon et al., 1992) , and its use in concurrent sound segregation is well established for stimuli where both within- and across-channel cues are available (Scheffers, 1983; Assmann & Summerfield, 1990) , the potential usefulness of within-channel cues has received less attention. We will address this issue using stimuli consisting of two harmonic complexes, each bandpass filtered identically but with slightly different F0s. In pilot experiments, listeners have been presented with a 500-ms harmonic complex, consisting of a large number of harmonics of 210 Hz passed through a bandpass filter. After the first 150 ms of this sound, a second complex, with the same level as the first and passed through an identical filter, was added; its F0 was either 175 or 252 Hz and its duration was 200 ms. The perceptual results of this simple manipulation were striking: when the filter cutoffs were set to 20 and 1420 Hz, so that the components of each sound were resolvable by the auditory periphery, listeners heard the second "target" sound as having a clear pitch. However, when the filter was set to 3900-5400 Hz, so that the components were unresolved, the target sounded distinctly aperiodic: a common description was that it "crackled". A roughly similar percept occurred when the duration of the 500-ms "masker" was reduced to 200 ms, so that the two complexes were turned on and off together.

Our perceptual observations have, to some extent, been reinforced by the results of a two-interval discrimination task, in which the target's F0 was lower than that of the 500-ms "masker" in one interval, and higher (by the same amount) in the other: listeners' ability to identify the interval with the higher F0 was measured as a function of the F0 difference (ΔF0) between the two targets. For the lower filter setting (resolved components), performance improved monotonically with increasing ΔF0, whereas for the higher setting (unresolved components), performance remained at chance even for the largest ΔF0 (32%) studied.

A2. Can We Extract the Periodicities of Two Overlapping Groups of Unresolved Components?

The above findings provide some tentative evidence that listeners are very bad at extracting the periodicities of two groups of unresolved components which occupy the same frequency region. The proposed experiments will test this preliminary conclusion, will obtain perceptual measures of the effect, and will explore the similarities and differences between these perceptual reports and the results of discrimination experiments. It seems likely that at least some aspects of the phenomenon can be explained using R. Patterson's auditory image model ("AIM"; see Patterson's section of this programme), whose triggering mechanism needs a regular, periodic input in order to form a stable image: the existence of more than one trigger per target period will prevent the target from being represented in a stable form. Our general approach will be to present our stimuli to a number of auditory models, in an attempt to identify the most convincing and parsimonious explanation for our results.

One reason for caution in accepting our preliminary conclusion is that when, in an additional condition of our discrimination experiment, the masker and target were turned on and off synchronously, performance for the unresolved components was better than in the "asynchronous" condition, in which the masker started before the target and ended after it. One explanation for this result is that listeners can extract the two envelope periodicities, but that the portion of the masker preceding and/or following the target (the "forward" and "backward" fringes) somehow reduced performance in the asynchronous condition. At present, we consider this second explanation unlikely, as it does not account for the fact that gating the masker asynchronously did not degrade performance for groups of resolved components. An alternative explanation, consistent with our preliminary interpretation, is that gating the masker and target synchronously caused them to become perceptually fused, and allowed listeners to base discrimination on the average F0 of the masker and target, which differed between the two intervals of each trial. We will perform two experiments designed to tease apart these two classes of explanation.

The first experiment tests one specific explanation, that of "backward recognition masking" (Massaro, 1975) , according to which the backward fringe of the masker interferes with the processing of the target's F0. We will determine whether the effects of masker gating are mainly due to the backward or to the forward fringe of the masker. Pilot investigations tentatively suggest that the forward fringe is the more important, a finding which, if confirmed, is inconsistent with backward recognition masking; "forward recognition masking" is a much weaker effect. Second, we will perform an experiment using asynchronous maskers in which the target will be presented at the same time as a third, "reference" group of components, and the task will be to say whether the target and reference groups are presented on the same, or different, F0s. Two conditions will be included: either the masker and target will be filtered from 3900-5400 Hz and the reference from 20-1420 Hz, or masker and target will be filtered from 20-1420 Hz and the reference from 3900-5400 Hz. Thus, in both conditions, the listener has to compare the F0s of two groups in the frequency regions 20-1420 Hz and 3900-5400 Hz; the conditions differ in which region contains the masker. If listeners can extract the F0s of two groups of resolved components in the same frequency region, but not those of two unresolved groups, then they should perform above chance only when the masker is in the 20-1420 Hz region. However, if the results of our sequential discrimination task were due to some effect of the forward or backward masker fringes on the memory for the target's F0, then listeners should perform above chance in both conditions of the simultaneous task.

A3. Resolvability or Absolute Frequency?

So far, we have discussed the effect of frequency region on our results in terms of the resolvability of components, rather than in terms of absolute frequency (such as might occur, for example, due to phase locking falling off at high frequencies). Our sequential discrimination paradigm will be used to distinguish between these two interpretations, by orthogonally varying F0 and frequency region.

A4. Refining Perceptual Measures of the "Crackle" Percept: Following on from our perceptual experiments with informal listening, we aim to provide a more quantitative measure of the "crackle" percept, so that its dependence on parameters such as frequency region, F0, and masker gating can be compared with the results of our discrimination experiments. One approach will be to ask listeners to rate the perception of the target on a continuous scale, ranging from "definitely a periodic sound" to "definitely a crackle". To accomplish this, we need to generate a sound which can played to listeners as an example of what is meant by a "crackle", and, for reasons of circularity, this demonstration sound cannot be any of the test sounds. We have informally observed that a crackle percept can be produced by a random train of equal-amplitude spikes, where the duration of each spike is 0.1 ms and the probability of a spike occurring in any 0.1-ms time bin is about 5%. We will describe in more detail the percepts generated by random spike trains in section D; here we simply point out that such sounds have a wider bandwidth than our mixture of two groups of unresolved components, but can capture the same "crackle" quality. In order to equate the audible bandwidths of the spike trains and harmonic complexes, both sounds will be presented in a background of continuous bandstop noise. A second approach will be to require listeners to match mixtures of one periodic complex and one spike train, to a mixture of two periodic sounds: again, both sounds will be presented in bandstop noise, and listeners will adjust the relative amplitudes of the periodic and aperiodic parts of the former mixture to sound "equally periodic" as the latter.

A5. Further Investigations:

Our new perceptual measures will be used, in tandem with our discrimination task, to investigate two further aspects of the phenomenon which have so far been observed only in informal listening. One of these is that, although a 200-ms target/masker mixture sounds aperiodic, increasing its duration to several seconds allows the listener to hear the two underlying periodicities. We will investigate the time course of the effect, which, if substantiated, would require a revision of existing auditory models, including R. Patterson's AIM and those based on correlograms (Slaney & Lyon, 1990; Meddis & Hewitt, 1991) . Second, when the masker contains a forward and a backward fringe, listeners report that they can hear its pitch continue throughout the (aperiodic sounding) target. However, it is not clear whether this information is genuinely preserved in the auditory periphery (such as might occur in the AIM if it continued to trigger on the peaks in the masker envelope), or whether it is merely an example of central perceptual processes "filling in" information which is no longer present (Ciocca & Bregman, 1987) . This will be determined by imposing frequency modulation (FM) on the portion of the masker preceding the target, but keeping that part of it which is synchronous with the target unmodulated. If information on the masker's F0 remains available during the target, then listeners should hear the modulation cease: if, however, they are simply filling in what the masker "ought to" sound like, then they should hear the modulation continue.

B. Within-Channel Processing of FM Incoherence *(Carlyon)*

When the fundamental frequency (F0) of a periodic sound changes, all the harmonics of that F0 change frequency coherently (in the same direction, at the same time). It has been suggested that listeners use this FM coherence to group together the commonly varying components of one sound, and to separate them perceptually from components of other sounds, which may be changing frequency differently. However, Carlyon (1991; 1994b) has shown that, for resolved frequency components, listeners cannot discriminate between coherent and incoherent FM, except by virtue of the fact that incoherently modulating one component of a harmonic complex causes it to become mistuned from the rest. He concluded that there is no across-frequency mechanism specific to the processing of FM incoherence. In those experiments, within-channel cues were eliminated, for fear that the subject would make the discrimination on the basis of some trivial aspect of the stimulus. In our new task, listeners will be required to compare the frequency of one component of a closely-spaced harmonic complex, modulated coherently or incoherently with the rest, to that of a subsequent tone presented in isolation.

In one condition, the first stimulus presented on each trial will consist of harmonics 14 through 26 of a 100-Hz F0, with the 20th harmonic (the "target") mistuned upwards on half the trials and downwards on the other half. All harmonics will be frequency modulated coherently by +/- 2.5% of their carrier frequencies, and at a rate of 2.5 Hz. The second half of each trial will consist of a single component, modulated at the same depth and rate as the target, but with a frequency which differs from it by plus or minus Δf Hz . In both conditions, the overall FM phase will be randomised from trial to trial, but the second, isolated, tone will always be modulated coherently with the target. The listener's task will be to decide whether the carrier frequency of the second tone is higher or lower than that of the target; the overall frequency will be randomised between trials in order to force the listener to make this comparison, rather than perform the task on the absolute frequency of the isolated tone. Existing data (Hartmann et al., 1990; Moore & Ohgushi, 1993) indicate that performance on the task will increase with increasing mistuning, and we will measure psychometric functions (d' vs. mistuning) to verify this, for a range of values of Δf.

In the second condition, the mistuning will be produced by modulating the target incoherently with the other harmonics. The FM incoherence will cause the target to become mistuned by an amount which varies sinusoidally throughout the stimulus, and which increases monotonically as the modulator phase disparity between the target and other components is raised from 0° to 180°. We will exploit the fact that it is possible to calculate the "equivalent maximum mistuning" produced by a given modulator phase disparity, and will measure sensitivity for a set of disparities which correspond to the mistunings used in the first condition. If FM incoherence provides a cue to segregation over and above the mistuning that it causes, then we might expect performance to be better in the second condition than in the first. If, however, FM incoherence is only effective because of the resulting mistuning, we would expect performance to be comparable, and for sensitivity to vary with "equivalent" mistuning in the same way in the two conditions -- in other words, the slopes of the functions in the two conditions should be similar (Carlyon, 1991) .

C. How Many F0-encoding Mechanisms are there? *(Carlyon)*

Traditional theory assumes that the mechanism used to estimate the F0 of low-numbered harmonics (which are resolved by the auditory system into separate frequency channels) is completely different from that used for the F0 of high-numbered harmonics, which are unresolved. In contrast, recent, more parsimonious, theories (including both AIM and the "correlogram" models) have proposed a common mechanism for deriving the F0s from both resolved and unresolved harmonics. Recently, Carlyon and Shackleton (1994) have presented evidence against this "single-mechanism" class of theory: although listeners are very good at comparing the F0s of two groups of resolved harmonics or two groups of unresolved harmonics, they are very bad at making the comparison when one group is resolved and the other unresolved. Those results are consistent with the idea that, when two groups of harmonics differ in "resolvability", they are processed by separate mechanisms, the outputs of which must be "translated" into a common format, and that this translation stage introduces a significant amount of inaccuracy into the comparison. This conclusion was backed up by a detection theory analysis, which compared sensitivity on the across-frequency ΔF0 task to that on sequential F0 differences imposed on the individual groups used in any one comparison. The purpose of the sequential task was to provide an estimate of the accuracy with which each group's F0 was encoded by the auditory system. The analysis showed that only when the two groups differed in resolvability was performance on the simultaneous across-frequency comparison worse than predicted from the "encoding accuracy" of individual groups.

Carlyon and Shackleton's findings have important implications for theories of pitch perception and of concurrent sound segregation, but are complicated by two factors, both of which can be overcome fairly straightforwardly. First, when listeners are asked to detect a sequential difference in the F0 of a group of resolved harmonics, they might perform the task simply by doing a frequency discrimination on the individual harmonics within that group: if so, they could "bypass" the F0-extraction mechanism, and performance on the sequential task would over-estimate the accuracy with which the F0 of resolved harmonics is estimated. This will be overcome by presenting only a subset of the harmonics in each group on any one interval, both for the sequential and the simultaneous comparisons. As the harmonics will differ on the two halves of each trial, listeners will be unable to perform the sequential frequency discrimination on individual harmonics, but will be forced to detect a difference in F0 per se. Second, when two groups of unresolved harmonics are present, there is evidence that listeners detect ΔF0s by virtue of the "pitch pulse asynchronies (PPAs)" that inevitably arise: the peaks in the waveform of the group with the lower F0 lag progressively further and further behind those of the upper group (Carlyon, 1994a; Carlyon & Shackleton, 1994) . This cue is not available when one of the groups is resolved (Carlyon, 1994a) , and is not available in a sequential comparison. The result is that, for unresolved harmonics, performance on the sequential task substantially under-estimates that on the simultaneous, across-frequency comparison, due to the existence of an additional cue in the latter task. Fortunately, the PPAs that result from a ΔF0 are small immediately after stimulus onset, and so they can be reduced by shortening the duration of the stimulus from 400 ms to 50 ms: if necessary, performance can then be increased to a measurable level by repeating the same 50 ms segment several times, without increasing the PPAs (cf. Assmann & Summerfield, 1994) . These two manipulations, combined with Carlyon and Shackleton's findings, should provide strong evidence as to whether the F0s of resolved and unresolved harmonics are encoded by the same, or by different, mechanisms.

D. Perception of Random Spike Trains *(Carlyon, Patterson)*

We have generated a continuum of sounds consisting of consecutive 0.1-ms time bins, in which the probability of any bin being filled with a spike (as opposed to silence) ranges along the continuum from 0.1% to 50%. At low probabilities (<1%, average interval between spikes > 9.9 ms), the listener hears a train of individual clicks, which turns into a crackle percept as the probability increases further. At still higher probabilities, one hears a "shhh" similar to Gaussian noise. This continuum of percepts has two implications for auditory models such as that proposed by Patterson. (i) Most temporally based models do a good job of distinguishing between periodic and aperiodic sounds; however, the "crackle" and the "shhh" are both aperiodic, and have similar bandwidths. Can the models reflect the difference in perception, and, if not, what modifications need to be proposed? (ii) The continuum reflects the operation of two types of temporal integration, with different time constants, operating on similar stimuli. One, with the longer time constant, relates to the transition between "multiple clicks" and a single crackle sound. The second, at the transition between the crackle and "shhh" percepts, has a shorter time constant. Our hypothesis is that, when several spikes occur within this short time window, the bimodal distribution of amplitudes in the spike train is converted to an approximately Gaussian distribution at the output of the window by the random nature of the spike generation process. The stimulus will allow us to measure the time constant of both types of integration over a wide range of supra-threshold levels, and will provide a strong test of the temporal integration parameters of existing auditory models. In particular, we will test the idea that the shorter time constant corresponds to the impulse response of auditory filters responding to the sound, by playing bursts of the sound in continuous notched noise. If so, then, as the centre frequency of the notch is increased, the shorter impulse responses of high-frequency auditory filters should cause the transition between the crackle and "shhh" percepts to occur at progressively higher spike probabilities.

VISUAL DISCOMFORT

(Wilkins)

A. A General Unified Theory

A general and unified theory of the neurological mechanisms underlying visual discomfort has been advanced in a book shortly to be published by Oxford University Press (1.1). In brief, the theory draws upon similarities between the visual stimulation that induces seizures in patients with photosensitive epilepsy and the visual stimulation that, in others, evokes perceptual distortion, eye-strain and headaches. According to the theory, the perceptual distortions are due to a localised and constrained hyperexcitability of neurones in the visual cortex. The distortions are associated with headache susceptibility in many different ways. They are also associated with susceptibility to one of the common cold viruses (respiratory cyncitial virus) which predisposes to asthma, with which migraine is statistically associated (1.20). The visual stimulation responsible for perceptual distortion is uncomfortable and interferes with the perception of other weaker stimuli. The extent of this interference is greater in people who suffer migraine (1.99).
The theory of visual discomfort has been applied to reading in two review chapters (1.71, 1.72), particularly in relation to the spatial aspects of text (1.88) and the complaints that surround the use of visual display terminals (1.33). The theory also provides a parsimonious interpretation of the therapeutic effects of ophthalmic tinting, suggesting a potential for therapy not only in reducing the perceptual distortion suffered by children with reading difficulty, but in preventing photophobia in migraine and reducing liability to photosensitive seizures.

The theory of visual discomfort has been applied to lighting in three review papers (1.34, 1.70, 1.90). Patients with agoraphobia have a sensitivity to light and, under double-blind conditions, their heart rate is affected by the imperceptible 100-per-second modulation of light from fluorescent lamps (1.12). This modulation has been measured for most types of commercially available fluorescent lamps (1.36), and the data thus obtained has been used to design an ophthalmic tint that reduces the modulation with a minimal effect on colour perception, and with a reasonably cosmetic colour appearance (1.42). This tint has been patented (1.122) and is marketed by Cambridge Optical Group Ltd. as the "Comfort 41". Large individual differences in preference for illuminant chromaticity have been demonstrated (1.92).

B. Precision Ophthalmic Tinting

Certain individuals, particularly those with a family history of migraine, report perceptual distortions of text when they read, sometimes sufficient to impede or impair reading (1.39). These individuals usually report that the perceptual distortions abate when the text has a particular colour, different for each individual (1.41). Individuals with a family history of migraine tend to report discomfort when the text has a reddish hue, a tendency that age and sex matched controls do not show (1.5). A simple but novel device (Intuitive Colorimeter) has been developed and patented (1.121). It illuminates a page of text with coloured light in such a way that the hue and saturation of the colour can be varied separately without an associated change in brightness (1.40). Small changes in colour can be evaluated whilst the eyes are colour-adapted. Colour constancy mechanisms do not complicate the judgement because all surfaces have even spectral reflectance. The analysis of the colour changes has involved a novel application of statistical methods which allow for circular rather than linear variables (1.4).

The Colorimeter provides a quick and accurate method of obtaining an optimal chromaticity for an ophthalmic tint, (1.38). A set of ophthalmic trial filters, included in the patent, has been designed in collaboration with Cerium Optical Group. The filters have one of seven hues, and there are five filters of each hue, with progressively increasing deposition of dye, each with a smooth spectral transmission. Using trial filters from only two of the seven hues, it is easy to obtain a combination of filters that resembles any chromaticity selected in the Colorimeter. Any chromaticity in a large gamut can be closely approximated in a filter that has a smooth spectral transmission, and that therefore minimises metamerism. Once a combination of trial filters has been selected, it can be ratified by the patient under normal viewing conditions. The Colorimeter and Trial lenses constitute a system for precision ophthalmic tinting. The system is marketed under license by Cerium Visual Technologies, together with a full instruction manual (1.116). The combination of trial lenses chosen by the patient forms a prescription that can be used by optometrists to specify the required spectral transmission. The dyeing is undertaken by Cerium. It is guided by eye, using a method which ensures that a visual match provides identical spectral transmission. The transmission is checked by a spectrophotometer and associated software (1.114) which provides quality control and prints a hand-out for the optometrist and the patient, describing various characteristics of their lenses, including the propensity to interfere with colour perception. The system has been evaluated with children who have reading difficulties, initially in an open trial (1.15) and, more recently, in a double-blind trial (1.37). In the latter trial the subjects were provided in turn with two pairs of spectacles, each pair having similar colour. One pair of spectacles matched the optimal Colorimeter setting, and the other pair matched a suboptimal setting at which perceptual distortions were apparent. Headache and eye-strain were reduced with the optimal pair, even though subjects were quite unable to give a preference, or to say which pair best resembled the Colorimeter setting.

This finding is counter-intuitive and suggests that the tints have an efficacy over and above that of any placebo. According to the theory of visual discomfort, the tints change the pattern of excitation in the visual cortex. The colour that minimises perceptual distortion is that which reduces the excitation in hyperexcitable areas. When this colour is provided by spectacles the neural network is then less at risk of an inappropriate spread of excitation.

C. Reading

The effects of colour on reading and eye-strain can also be evaluated using plastic sheets placed over a page of text (overlays), although the optimal colour differs from that for ophthalmic tints. A set of overlays that can be used to sample colour space evenly and efficiently has been designed (1.35), and is now marketed by the Institute of Optometry Marketing together with a manual describing their use (1.117). Overlays can improve visual search by a small margin but their greatest benefit would appear to be in reducing the symptoms and signs of visual discomfort from prolonged reading (1.26).

D. Photosensitive Epilepsy

The extensive empirical data on photosensitive epilepsy which forms the basis of the theory of visual discomfort has been reviewed in a book chapter (1.73) and it forms the substance of a report commissioned by the Department of Trade and Industry on Photosensitive Epilepsy Associated with Playing Computer Games (1.118). The response of photosensitive patients to new forms of video technology is being studied (1.14). The work has also been reviewed for the benefit of sufferers (1.115).

E. Other Work on Visual Perception

The evaluation of the Cambridge low contrast gratings in various clinical contexts has continued (1.21). In addition, the visual processes involved in rehabilitation have been reviewed (1.60).

F. Industrial Collaboration

The Comfort 41 lens is being marketed by Cambridge Optical. The Intuitive Colorimeter has been manufactured in collaboration with Cambridge Industrial Design and Wilj International, and is now marketed under license by Cerium Visual Technologies. The MRC tinting system which incorporates the Intuitive Colorimeter and tinted trial lenses was launched in the summer of 1993 and is now in use in more than 40 optometric practices in the UK. It is being marketed in Europe, the United States and Australia. The Intuitive Overlays are marketed by Institute of Optometry Marketing and have already been reprinted.

FUTURE PROPOSALS

A. A General Unified Theory

One of the difficulties with the assessment of visual discomfort is that the assessment is necessarily subjective. It is unsatisfactory to rely on reports of sensations for which there is no external validation, and no objective criterion. We propose a series of investigations designed to establish objective correlates of visual discomfort and to advance our understanding of the physiological basis of the discomfort.

A1. Visual Evoked Potentials:

The theory of visual discomfort proposes that perceptual distortions arise from a cortical hyperexcitability. This hypothesis can most obviously be tested by using visual evoked potentials. Evoked potentials have been shown to be abnormal in migraine, and have a particularly high amplitude in response to flicker at epileptogenic frequencies. Recent work has highlighted abnormalities in dyslexia, although these remain controversial. Kuba and colleagues (personal communication) have used visual stimuli that can be seen only by virtue of their movement, and report that the potentials evoked by these stimuli may demonstrate unusually large abnormalities in a variety of clinical contexts, including dyslexia. It is proposed to study the potentials evoked by flicker, by pattern reversal and by pattern movement in patients who find tinted glasses beneficial. The potentials obtained when the stimulus has the preferred chromaticity will be compared with those obtained when the chromaticity is complementary and when the chromaticity is similar to those of conventional illuminants. These studies will require the purchase of a system for evoked potential monitoring. They offer the possibility of an objective correlate of physiological functions that at present can be measured only with subjective methods.

A2. Functional Magnetic Resonance Imaging:

In collaboration with colleagues at Cambridge University Department of Medicinal Chemistry, it is proposed to use fMRI to study the cerebral response to a variety of visual stimuli. We propose to measure regional cerebral blood flow in visual cortex when observers view epileptogenic patterns. If the patterns are presented in one lateral visual field, and the other field contains an innocuous pattern, the activation in the two hemispheres can be directly compared. The theory of visual discomfort predicts that migraineurs who experience consistently lateralised visual aura may show relatively increased blood flow when the stimulus is presented in the same field as that in which the aura occurs. If the metabolic response to epileptogenic stimuli is large, it would be instructive to study individuals without migraine who suffer pattern glare.

A3. Other Objective Correlates:

Three further avenues will also be explored in the hope of obtaining objective correlates of visual discomfort.

A3.1 Visual masking:

The visual stimuli that give rise to discomfort are effective at masking low-contrast targets (1.99). It is hoped to develop a clinical test of masking that will be useful in the assessment of patients who complain of discomfort.

A3.2 Pupil size:

Under photopic levels of luminance, pupil area has been shown to be determined largely by the scoptopic luminance. It is proposed to measure the effects of tinted lenses on pupil size to see whether this might provide one explanation of their benefit in reducing photophobia and increasing visual clarity.

A3.3 EMG:

EMG power recorded from temporalis muscle has been shown to correlate highly with reports of glare from light sources close to the visual axis. It is proposed to record EMG activity when patients observe stressful patterns and to do so when the patterns are illuminated by light of a chromaticity that reportedly reduces the stress. This study will require the system for electrophysiological monitoring mentioned in A1.

A4. Lighting:

The theory of visual discomfort has been applied to lighting design, but to date, the emphasis has been on the effects of the rapid temporal modulation of light (e.g. Wilkins, Nimmo-Smith, Slater & Bedocs, 1989). It is proposed to continue the work on flicker, but also to extend the theory to encompass the effects of the spectral power distribution.

A4.1 Interaction between flicker from displays and that from lighting:

The refresh frequency of computer displays has been increasing, bringing it closer to the frequency at which office lighting has its predominant modulation. It is possible that there exists an interaction between the modulation from both sources. Visual adaptation to the "beat" between two high-frequency sources can be demonstrated psychophysically providing evidence that the "beat" may be a potential source of discomfort. It is proposed to measure movements of the eyes across computer displays under lighting which does and does not exhibit the typical 100Hz modulation. This modulation can be removed using high-frequency fluorescent ballasts, and may reduce eye fatigue in offices where computer displays are in frequent use.

A4.2 Individual differences in colour constancy:

Preliminary data have indicated that, when looking through a coloured lens, some individuals are unable to tell that it is coloured, even when the lens is very strongly saturated. It is already evident that there are large individual differences in this respect. These findings suggest that some individuals are far more affected by changes in illuminant chromaticity than others. We hope to explore these individual differences to determine whether they relate to discomfort and to the effects of the chromaticity on spatial vision.

A4.3 Ultraviolet radiation:

Recent informal observations have suggested that, under double-blind conditions, observers can detect the difference between filters that block UVA below 400 nm and those that block below 380 nm. The discrimination is made not on the basis of colour appearance but of visual discomfort. If confirmed, this observation may be of relevance to the use of UV-blocking dyes in ophthalmic lenses and to the increasing prevalence of lamps that emit ultraviolet light.

B. Precision Ophthalmic Tinting

The MRC system for Precision Ophthalmic Tinting was launched commercially in the spring of 1994. There are preliminary indications that precision tinting may offer benefits in reducing the photophobia associated with a range of different disorders, including not only dyslexia but migraine, head injury, and photosensitive epilepsy. It is proposed to set up clinical trials, in collaboration with colleagues. The majority of trials will be open and, if the results appear promising, will be followed by double-blind trials.

B1. Double-Blind Trial of Precision Ophthalmic Tinting in Migraine:

The indications for precision ophthalmic tinting as a treatment for photophobia have already been reviewed (1.91). A double-blind trial in migraine has been designed and is awaiting funding.

B2. Precision Ophthalmic Tinting in Patients with Head Injury:

Many patients with closed head injury report photophobia, particularly immediately following the trauma. I have began an open trial to assess the clinical impact of precision tinting in these patients. If the initial results continue to be successful, I shall organise a clinic in collaboration with colleagues in optometry and in rehabilitation.

B3. Open Trial of Precision Ophthalmic Tinting in Photosensitive Epilepsy:

Thus far, 12 patients with photosensitive epilepsy have been offered precision tints. Six have benefited. It is proposed to extend this trial and to explore ways in which colorimetry, currently available only in optometric practice, can be made available in the clinical neurophysiology laboratory for the assessment of patients with epilepsy. I hope to establish a clinic, with Dr David Fish at the National Hospital, at which a colleague in optometry, Anita Lightstone, will assist with the assessment of patients.

C. Reading

The theory of visual discomfort has been applied to reading. The effects of high frequency modulation of light on the control of eye movements have been studied, but the theory predicts that repetitive spatial modulation may also have deleterious effects. It is proposed to explore the effects of such spatial modulation on ocular motor control. It is also proposed to investigate the visual factors that contribute to stress when children learn to read.

C1. Eye Movement:

Eye movements are often studied in response to isolated targets rather than the spatially ambiguous stimulus provided by text. It is now known that rapid eye movements made to one of two neighbouring objects in the periphery of vision are inevitably directed to a intermediate position between the objects. The implications of this so-called "global effect" for movements of the eyes across text are obvious. It is proposed to investigate movements of the eyes across text that has been set so as to enhance or reduce the information available at low spatial frequencies.

C2. Contrast of Letters:

Paper used in the production of children's reading books incorporates fluorescent dyes that absorb ultraviolet light and re-emit in the visible range, giving the paper a "whiter than white" appearance. This potentially increases the contrast of print, already high because of laser typesetting. I hope to measure the fluorescent response of typical dyes and any enhancement of contrast they produce under typical conditions of illumination, and thereby to assess the likely impact on contrast and, by implication, on children's reading.

C3. Group Tests for Overlays:

One hundred and fifty five normal 7-year old school children have been examined individually with coloured sheets of plastic placed on a page of text (overlays). Forty-five percent reported improved perception with a colour, and most have subsequently used the chosen overlay without prompting for six months. Now that the MRC overlays are commercially available, it is important to ensure they reach the children who can benefit from them. It is also important to minimise the demands on teachers' time. In order to reduce the amount of individual assessment that is necessary, we are developing group testing methods. Preliminary data suggest that the majority of children who will not benefit from overlays can be detected by group testing methods. It is proposed to refine the present methods and improve their sensitivity and selectivity.

C4. Referral Structure:

It seems likely that the overlays provide a way of selecting those children who may benefit from coloured glasses, but this has yet to be demonstrated formally. There is much work to be done refining the techniques for assessment.

D. Photosensitive Epilepsy

It is proposed to investigate the physiological basis of scotosensitive epilepsy, contrasting it with photosensitive epilepsy. Trials of precision tinting are proposed, together with a study of the effects of fluorescent lighting on photosensitive epilepsy.

D1. Scotosensitive vs. Photosensitive Epilepsy:

Certain patients with idiopathic epilepsy exhibit occipital spikes that are present only when the patient is unable to see patterned vision (so-called "fixation-off sensitivity"). Curiously, these patients are not sensitive to flicker. The division of magno- and parvo-cellular visual pathways may offer one possible explanation. In collaboration with colleagues at St Thomas' Hospital, the physiological mechanisms of fixation-off sensitivity will be explored and contrasted with those of photosensitive epilepsy.

D2. Open Trial of Precision Tinting. See B3 above

D3. High-Frequency Flicker and Epilepsy:

There has been little study of the effects of high-frequency flicker on epilepsy. It is proposed to record the EEG of patients who are undergoing routine clinical telemetry in the course of treatment for epilepsy, comparing the incidence of epileptiform EEG activity when the recording suite is illuminated by conventional fluorescent light, and when, under double-blind conditions, the lighting is controlled by high-frequency circuitry that removes the 100Hz flicker.

MOVEMENT CONTROL *(Goodrich, Nimmo-Smith, Sellen, Tresilian, Wing)*

Introduction

Five themes touching on the work of several APU scientists are covered under the heading of movement control. The first covers variability of the two elemental characteristics of movement, force and time. The next three themes cover the related skills of reaching, catching and grasping with position coming to the fore as a critical task element added to force and time. Standing balance is treated in the fifth section.

A. Elemental Variability

Movement results from muscle activity producing force of a given magnitude that acts on the mass of the limb, possibly with the mass of an object to be moved, for a certain duration. With a fixed starting position, fluctuations from one occasion to another in either force or duration will result in a range of end positions. This section is concerned with theoretical accounts of variability in these elemental aspects of movement.

A1. Force:

It is surprising, given the elemental status of force in movement, that there has been relatively little research into force control, and this is particularly true with regard to variability. APU research focuses on isometric force control because this simplifies measurement and also is likely to reduce the non-linearities in tension development by muscles undergoing length changes.

A1.1 Parallel Force Unit Model (PFUM) (Wing; Collaborator: Ulrich): Wing has completed a series of studies to examine the form of brief (300 ms) force impulses in terms of the mean and variability of the force-time function. A motivating factor for the work has been a mathematical model, PFUM, in which it is assumed that observed force arises from summing a large number of independent force units with variable times of activation relative to a single central command (1.27). The resulting rise and fall of force depends on both the form of the force-time function of the individual units and the distribution of their onset times. PFUM predicts scaleability of form; the basic shape of the force-time function should remain the same whatever the peak force. The model also predicts that the force-time variability function may show a local minimum at maximum force. These predictions have been supported in a series of experiments (1.57, 1.67) with analyses that included the novel use of centralised moments as force-time waveform shape descriptors.

A2. Timing: The timing of movement may be studied by asking subjects to make periodic responses to define a time series of inter-response intervals. A fundamental premise is that variability in the intervals reflects the structure of underlying timing mechanisms.

A2.1 Individual timing of series of movements (Nimmo-Smith, Wann, Wing; Collaborators: Vorberg, Bisiacchi):

In a theoretical review, Wing (1.68, 1.69) set out a number of linear models as extensions to his original two-stage model (in which it was assumed that inter-response intervals reflect two independent sets of underlying delays, one arising in a central timekeeper or clock, the other in motor implementation processes). One extension posited hierarchically organised timekeeping, with nested clocks responsible for timing groups of responses. It was shown on the basis of existing data that this extended model holds for the production of musical rhythms but is rejected in the case of another keyboard skill, typing.

This pattern of results suggests that a distinction should be made between musical performance skills, where response timing is an explicit goal, and skills in which timing is an emergent feature rather than a requirement of the task. This limitation on the applicability of hierarchical timing also applies to handwriting. Contrary to earlier suggestions in the literature, Wann and Nimmo-Smith (1.31) found that the relative durations of pen strokes change with writing size, which violates hierarchical timing. In a further study, however, Wann and Nimmo-Smith (1.32) found that writing on a smooth surface, which tends to make the pen skid faster over the surface, results in subjects using greater pen pressure. This has the effect of increasing friction, so keeping pen velocity -- and hence timing of strokes -- relatively constant. A number of other issues relating to handwriting variability were reviewed by Wing (1.2, 1.28, 1.29, 1.75, 1.77).

If musical rhythm production involves hierarchical organisation of a number of clocks, this might be expected to make greater demands on cognitive resources than regular, equal-interval tapping. This suggests that a given interval might be produced with greater variability in a rhythmic context than when that same interval occurs in an isochronous sequence, a prediction supported by a study by Wing and Bisiacchi. Moreover, the implication that cognitive load is greater in producing a rhythm was reinforced by the finding that the effect of context (rhythmic vs. isochronic) interacted with the performance of secondary tasks, such as backward counting.

A2.2 Ensemble timing (Wing, Allison, Woodburn):

An important concept in the hierarchical timing model is that information about overall rate is passed down through the hierarchically nested clocks. This constitutes a 'classic' information processing model in the sense that unobservable stages are assumed whose existence can only be inferred indirectly (from the statistical dependence structure of the data). There are however situations involving human timing where the timekeeping elements are directly observable, namely, ensemble timing.

An example of ensemble timing is rowing: for individual oarsmen in an eight, the task may be defined as producing oar-strokes at regular intervals in phase with the other crew members. The relevance of rowing to the hierarchical timing model stems from the fact that the stern-most oarsman ('Stroke') sets the rate for the others. Because the line of vision in a racing shell is restricted, it is likely that timing information propagates along the shell from one oarsman to the next. Indeed a preliminary study (1.93) showed a between-oarsman correlation structure indicating that the information passes down each side of the shell separately, with Stroke sitting at the apex of the branches of a hierarchy. A second study (1.58) also showed between-rower correlations but there were no differences according to side of the shell. One possible reason for the discrepancy is that the crew in the second study were more experienced. They may have based their coordination on multiple cues available to all rowers simultaneously which would have removed any tendency to a side-specific statistical structure to the interstroke intervals.

B. Reaching

Consider reaching for an object; movements of the fingers open the hand at the same time as shoulder and elbow movements carry the arm forward. Although there is no mechanical linkage between the fingers, shoulder and elbow (so that independent movements of hand and arm can be produced if desired), in reaching there is usually a tight temporal coupling between them. In asking what is the basis of such coordination, it should be noted that movement variability and, in particular trial-to-trial covariation, can provide important clues. This was a central thesis of Wing's tutorial review of 25 years of motor control research in Attention and Performance (1.43).

B1. Hand Positioning after CVA (Wing, Lough; Collaborators: Fraser, Turton, Jenner):
Moving the hand between two points in space requires various contrasting patterns of coordinated shoulder and elbow movements. For example, moving the arm across the front of the body involves simultaneous shoulder and elbow flexion, whereas a forwards movement starting at the body midline requires extension of the elbow with flexion of the shoulder. Clinical observation of arm movement after a CVA has led to the suggestion that flexor or extensor synergies predominate (so that midline movements are difficult to perform). In a longitudinal study of stroke patients, Wing and Lough (1.47) sought a quantitative description of this limitation on coordination. Motion of the elbow joint was examined in stroke patients when they made movements in a horizontal plane with arm supported against gravity. Targets were positioned so that flexion, extension or absence of motion at the shoulder was required. There was no reliable influence of shoulder

motion on elbow movement, nor did this picture change with time following stroke onset. Thus there was no support for the fixed synergy view, and it may be that the clinical impression of stroke patients reflects salient changes in resting posture in response to gravity rather than alterations in coordination in active movement.

B2. Hand Shaping in Prehensile Reaching (Wing, Haggard; Collaborator: Jenner):

Picking something up requires an approach by the arm coordinated with hand opening to encompass the target object. Wing (1.74) reviewed a case study which showed that a user of an artificial hand employed a pattern of coordinating hand opening with arm movement that was the same in both the artificial and the natural hand. This similarity was observed despite quite different musculature being used to control the artificial hand. It suggests that action is specified in terms of motions in external space rather than being based on a joint/muscle representation of action.

With arm motion impaired in the artificial hand, it is interesting to note that the artificial hand opened relatively wider in approaching an object of given diameter. This suggests there was strategic compensation by the hand for limitations on arm movement. This was also reported in another single case study, this time of a cerebellar patient (1.9). Capitalising on the asymmetry of the patient's symptoms, Haggard and Wing showed that ataxic arm movement is associated with wider hand opening. An important double dissociation between the components was obtained when the patient was asked to reach in the dark. This improved position control of the ataxic arm but resulted in less accurate movement of the other arm. There were complementary changes in maximum hand aperture and this emphasised the strategic nature of coordination. A further example of the dependence of hand shaping on the transport component was found in a study in which normal subjects were asked to pick up an object after traversing an intermediate spatially specified "via" point (1.50, 1.59, 1.100). Compared to movements in which the subject was free to move the hand along a straight line path, shaping was significantly delayed.

The above experiments were based on naturalistic manipulation of hand/arm coordination. An alternative approach is to interfere with one component and assess effects on the other. An example of this approach involved innovative use of a linear actuator. The actuator was used to slow down the hand transport component of reaching by the arm to see whether and how the hand would adjust its shaping (1.11, 1.100). It was found that perturbation of transport typically elicited (after a delay comparable to a normal RT) a slowing or a reduction in hand aperture. A formal model with spatially-based coupling between hand and arm movement has been developed to account for these results (1.51, 1.100).

The measurement of movement in reaching can be a time consuming process when it is based on hand-digitised, frame-by-frame video analysis. Recent research at the APU has been considerably facilitated by a computer-based tracking system (Watsmart) although certain problems with the method had first to be surmounted (1.10)

B3. Bimanual Positioning Control for Computer Input (Sellen; Collaborator: Buxton):

The hypothesis underlying Sellen's work is that the sensorimotor configuration of human-computer interaction influences cognitive aspects of human performance (and vice versa). The broad goal is to understand the relationship between the sensorimotor and the cognitive aspects of interaction in order to develop innovative computer input techniques and devices. Sellen has examined compound tasks involving two-handed input (1.83). The starting point was Guiard's (1987) observation that in most everyday bimanual tasks, the actions of each hand tend to be different but interdependent. Three different bimanual techniques for accomplishing a computer task were compared: in one, the two hands controlled independent subtasks, and in two others the action of the right hand depended on that of the left hand. Results showed that one of the two dependent bimanual techniques resulted in significantly faster performance and lower cognitive load than either of the other techniques. The independent bimanual technique, however, was no faster and resulted in higher cognitive load than a conventional one-handed technique.

C. Interception

Many actions such as catching a ball require very accurate spatio-temporal coordination of the hand with a moving target object. In this section, we focus on what visual information is used to control hand motion in space and time. First, the stationary observer is treated; the ball's trajectory requires positioning of the arm only, and movements typically last a few hundred milliseconds. Second, the situation is considered in which there is motion of the whole body and this must be controlled relative to a moving target over periods of several seconds.

C1. Catching (Tresilian):

A new theory has been developed to account both for the timing skills shown in the execution of interceptive actions and for the timed responses and relative time-to-collision judgements obtained in laboratory tasks (1.25, 1.55, Tresilian, 1991). This new theory raises a host of new empirical questions. An attempt to use existing published data to address some of these has been attempted (1.22) though it was concluded that existing empirical studies are either inadequate for this purpose or have failed to control important factors.

Drawing on the early work of Lee (1976) as well as upon logical arguments, the theory proposes that interceptive actions are timed using perceptual information about time-to-collision (TTC). Geometric analysis has revealed that numerous sources of such TTC information are available to an observer, some of which are appropriate for object motion and others for observer motion (1.24). Thus, in distinction to Lee's work, the theory stresses multiple sources of TTC information, context- sensitive processes for selecting and combining the different information sources and the role of multiple sensory systems. Experimental work has confirmed some predictions based on these ideas (1.23).

In the new theory an important distinction is proposed between extrapolation and relative TTC judgement tasks (in which cognitive operations on the perceptual input are implicated) and fast interceptive actions (implicating a direct low-level coupling of perception and action which bypasses cognitive operations). A strategy for modelling the latter kind of process has been proposed and a detailed model for the visual regulation of timing has been developed using the equilibrium point hypothesis for motor control. The model has been used to simulate the effects of the following factors on the temporal precision and movement kinematics of interceptive actions: (i) the nature of the control scheme (continuous, intermittent or preprogrammed); (ii) neural transmission delays; (iii) low-pass filtering characteristics of the human visual system's response to image motion; (iv) perceptual threshold characteristics; (v) limb dynamics; and (vi) the sluggishness of muscle response to neural input signals due to the dynamics of the excitation-contraction coupling process.

C2. Servo Control Schemes for Braking and Intercepting (Tresilian):

The evidence from fast interceptive actions suggests that they are controlled by predictive information in the spatial domain as well as in the temporal domain discussed in the previous section. There are actions involving moving targets (or the observer moving relative to stationary targets) which evolve over periods of seconds rather than milliseconds, and it has been proposed that control of two such actions -- braking and running to catch a ball -- are controlled using a servo type strategy which does not involve predictive information (Lee, 1976; Chapman, 1968).

Both Lee's and Chapman's proposals involve the person attempting to maintain visually measurable quantities at fixed values throughout performance of the action; successful performance is guaranteed if the person is successful in keeping these quantities sufficiently close to their desired values. An obvious prediction, therefore, is that during braking or running to catch a ball, the relevant quantities will be close to their theoretically desired values throughout performance; this prediction has been confirmed both for braking and catching (e.g. Lee, Reddish & Rand, 1991; Dienes & McLeod, 1993). However, modelling of these tasks has revealed that this type of data is quite insufficient as a test of these servo control hypotheses because maintenance of the relevant quantities close to their theoretically desired values during performance is also a prediction of other braking and catching strategies which involve predictive information (1.56).

D. Grasping

If a subject is asked to move a grasped object, accelerating then decelerating the hand induces reactive forces on the object and these add to the gravitational load (i.e. object weight) exerted on the hand. The problem for the motor system is that the grip force used when holding an object at rest is not, in general, sufficient to withstand the additional reactive forces and so these may result in the object slipping. The psychological interest is that the necessary compensation can be anticipated as it is a function of perceivable object attributes (e.g. mass, friction) and the nature of the planned movement (e.g. acceleration level). The study of grasp during movement is a new area, significantly extending the 'classic' analysis (by the Umea group: Westling & Johansson 1984) of the loading phase of grasping an object. An important contribution to this research has been the development of a simple but reliable means of recording grip force and movement. This involved using an accelerometer attached to a force transducer so that acceleration and deceleration are measured orthogonal to the grip force produced by the precision grip acting on the force transducer.

D1. Anticipatory modulation of grip force (Wing, Tresilian; Collaborator: Flanagan):

Research at the APU on grip adjustments for rapid arm movements has shown that people anticipate self-induced loads and compensate for them by adjusting grip force up and down in parallel with the load forces induced by the arm kinematics (1.7, 1.8). The grip force adjustments are remarkably robust. Increases and decreases in grip force with modulation of acceleration persist throughout cyclic movement even though it might be thought simpler for the nervous system to raise the grip force to a new higher level (1.48). The adjustments in grip force are seen across a variety of grasps formed with different effector combinations and can also be observed when the acceleration arises from whole body and not just arm motion (1.6). This suggests that setting of grip force is muscle independent and is therefore likely to be represented at a relatively high level. However, the relevant processing module appears cognitively impenetrable in that people are apparently unable to exert conscious suppression of grip force adjustments associated with arm movement.

D2. Sensory Factors in Grasp (Wing, Allison; Collaborator: Flanagan):

The grip force required to hold an object depends on its surface roughness as well as on its weight. It is therefore interesting to ask whether weight judgements might be influenced by surface texture. In fact, a recent experiment (1.49) has shown that a smooth object is judged to be heavier than a rough object of equal weight. This suggests that efferent commands are used in weight judgement, and that the brain fails to differentiate efferent commands to the hand (responsible for grip force) and the arm (responsible for the lift force).

E. Standing Balance

The maintenance of upright posture involves an equilibrium of static and dynamic forces. The sum of external forces acting on the body may be represented as a vector through the body centre of mass (CM), which is located approximately in the middle of the body at waist height. If the vector projects outside the base of support provided by the feet, motion results and can lead to a fall. To counteract this possibility, advance compensatory action may be taken -- such as leaning to move the CM -- so that when the force vector direction changes, it continues to project within the base of support. The position of the CM is therefore of considerable importance to maintenance of balance.

E1. Weight Distribution (Wing, Barton):

When the only force acting on the CM is gravity, the distribution of the weight of the body between the feet is a good index of CM position. A special piece of apparatus, SwayWeigh, has been developed by Wing and Barton (1.123) to provide a portable, low-cost and reliable means of measuring weight distribution. The design of

SwayWeigh allows it to be used both for biofeedback purposes and for clinical scientific measurement. A useful feature in respect of the latter application is that it can be switched to measure fluctuations in weight distribution (wobble) which reflect active adjustments to posture in maintaining balance. A further feature is that all measurements are electronically scaled to bodyweight which makes them easier to compare. SwayWeigh has now been taken up commercially.

E1.1 Compensating for changes in CM position (Wing, Barton; Collaborators: Turton, Howick):

Consider the situation in which one arm is held up and out to one side and kept in that position. Compared to arms by the side, the raised arm leads to a small displacement of the body CM towards the edge of the base of support. This reduces the safety margin for overbalancing. A large scale study was conducted at a British Association for the Advancement of Science science fair to address the interesting question of whether posture is adjusted for this change in static equilibrium conditions. The results showed that people do correct for the effect on left-right weight distribution of holding an arm out, probably by leaning away from the raised arm (1.44).

To explore this aspect of balance control further, another experiment has assessed weight distribution when subjects are asked to hold a 5 kg weight in one hand, arms by the side, which induces a shift in whole body CM position similar to raising one arm. Interestingly, the results were instruction-dependent. If asked to stand 'upright', subjects tolerated the resulting shift in weight distribution, probably using vestibular or visual cues to maintain posture. However, if asked to stand with 'even' weight distribution, subjects could do this, suggesting an ability to access cutaneous or proprioceptive information from the lower limbs.

E1.2 Balance in the elderly (Maylor, Wing):

An increased incidence of falls in the elderly is associated with decreased postural stability. Maylor and Wing have been studying the possible relation between standing stability and cognitive task performance in the elderly. Standing balance in middle-aged and elderly volunteers was measured using SwayWeigh in the anterior-posterior direction. As might be expected, the elderly were significantly less stable than the middle-aged. In addition, there was also evidence of greater between- and within-subject variability in the older group. However, there were qualitatively similar changes in stability across the two age groups as a result of (1) raising and lowering the arms, and (2) standing for a long time. In contrast to these additive effects of age on stability as a result of physical changes, performing certain additional cognitive tasks produced interactive effects. For example, differences in stability between the middle-aged and elderly increased significantly when subjects simultaneously performed the Brook's spatial memory task. In contrast, random digit generation did not produce such an interaction. This suggests that, although standing balance is normally a highly automatic function, in the elderly it draws on cognitive processing resources; when these must be shared, balance performance declines. From the pattern of tasks that interacted with balance, one possible candidate is the visuo-spatial sketch pad of working memory.

E2. Standing Balance after Stroke*(Wing, Goodrich; Collaborators: Jenner, Burgess-Limerick, Clapp, Virji-Babul, van Vliet):*

Impairment of sensorimotor function commonly results from a CVA and can have profound effects on standing balance. Our experience with SwayWeigh, combined with an interest in impairments in balance after stroke, led to a review of the literature which showed the potential benefits of weight-shift training using biofeedback from devices such as SwayWeigh (1.76). However, methods for assessing impaired stability after stroke are lacking. Research on standing balance usually involves perturbing balance by displacement of the support surface under the feet. A novel alternative technique which involves applying controlled horizontal forces at waist level has been developed (1.45). The method has the advantage of allowing the effects of application and removal of force to be examined separately, which is not the case with support surface displacements. It is also particularly appropriate to the study of balance after stroke because it affords the possibility of stabilising the patient after a push if the hip position indicates instability and possibility of falling.

An initial study (1.46) of stroke patients using sideways forces at waist level has shown that they are less stable, particularly when the induced sway is towards the more affected side. A comparison of force application and force removal showed that the latter caused more problems. The individual patients were also documented in terms of their performance of various functional balance tasks. To score these, a procedure was developed based on averaged ratings obtained from groups of judges. A number of issues concerning ratings of motor impairment are covered in a collaborative study by Goodrich (1.13).

Over trials, the stroke patients in the previous study tended to improve in their ability to cope with destabilising forces, which suggests therapeutic effects of having balance gently probed. In this respect it is relevant to note van Vliet and Wing's (1.30) suggestion that, if robotic devices could be engineered to assist voluntary movement, they might serve a rehabilitative function in allowing physically handicapped users to explore altered relations between action and sensory consequences.

FUTURE PROPOSALS

Introduction

The proposals for future work on movement control develop the five themes covered in the last 5 years. A new area of proposed work, on proximal and distal anticipatory postural adjustments, will explore commonalities between the stabilisation functions of grasp and standing balance.

A. Elemental Variability

Variability in the timing of muscle activity (which affects duration and relative phase) or in the level of activity (which affects force) is an important constraint on the accuracy of ballistic movement. There is a fundamental division in the study of movement timing, between central and peripheral processes acting as separate variance sources. Wing will extend this distinction to the production of brief force impulses, by adapting an experimental paradigm used in timing studies in which subjects make repeated simultaneous responses with two bilaterally symmetric effectors. When timing is the focus of interest, common variation in the (within-hand) intervals between left-left and right-right responses is taken to represent variability in a central process that sets up a common command to the two effectors (1.69). Variation in the (between-hand) difference between response times (left-right asynchrony) is taken to reflect variability in separate peripheral control mechanisms for the two effectors. By making force the focus, with a single target peak force for left and right hand responses, common variation in observed force may be taken to represent variability in a central process that sets up a force command that is common to the two effectors. Variation in the difference in force between response pairs is taken to reflect the sum of variability in two separate sets of low-level processes associated with response execution.

A1. Force

A1.1 Parallel Force Unit Model (PFUM) (Wing; Collaborator: Ulrich):

Work will continue with PFUM, which comprises a specific type of peripheral variation in force. In PFUM the underlying force elements are assumed to act unidirectionally; a force impulse results from the summation over a large number of elements, whose duration may vary, but whose contribution is all positive. However, consider an observation of zero force. This may either indicate there is no muscle activity or that there is activity in opposing muscle groups, each group contributing equal torques of opposite sign with a net result of zero force. The utilisation of opposing muscles in the generation of brief force pulses will be investigated by asking subjects to vary the degree of agonist-antagonist co-contraction. Pilot work has shown this may be achieved by asking the subject to stiffen the joint, using surface electromyography (EMG) to monitor muscle activity. The mean and variance functions of the force impulses will be examined in relation to the level of antagonist contribution. PFUM will be extended by the inclusion of negative force units whose recruitment may be coupled in varying degree to the positive units.

A1.2 Bilateral force impulses (Wing):

Subjects will be asked to hold two force transducers, one in each hand. In one paradigm, they will produce brief force impulses to match targets defined in terms of peak force and duration or impulse. In a second paradigm, subjects will maintain a steady force on which they superimpose step increases or decreases to match target force steps. In either paradigm the target will be kept constant over a series of trials. Serial statistics will be estimated including covariance in force measure between the hands (central variance) and variance of the difference in force produced by each hand (twice the peripheral variance). The two paradigms will be checked for consistency of the within-subject estimates of the two parameters in the model.

Tasks that load central and peripheral processes differentially will be employed to demonstrate dissociation of effects on the variance estimates. Loading of the central process will involve varying the target force between a number of remembered values during a series of trials. Peripheral component variance will be manipulated by varying the baseline force or by changing the effector pair. Dissociations between central and peripheral force processes will also be sought by asking subjects to carry out the bimanual force production task while performing concurrent secondary tasks that differentially affect central and peripheral factors.

A2. Timing

A2.1 Individual timing of bilateral responses (Wing):

The work in timing will parallel that described for bilateral force impulses. Vorberg and Hambuch's (1984) study of synchronous bimanual tapping will be replicated and extended by including manipulations designed to load (common) central or (lateralised) peripheral processes contributing to timing. The central component will be loaded by requiring rhythmic patterning of repetitive responding. Changes in the peripheral component will be induced by varying the movement distance. The limiting case is no movement in which "tapping" involves isometric force pulses. Investigation of this case will allow evaluation of the response, both in terms of the time intervals between responses and their force. Cross-correlations between force and timing components will be estimated while varying emphasis is placed on force and timing targets. The goal will be to evaluate the modularity of these two elemental components of motor control.

A key assumption in the proposed research on timing and force control is that bilateral simultaneous movements are triggered by a common command. This constitutes a hierarchical perspective on motor control, and may be contrasted with a distributed control view of simultaneous responding which holds that each effector is driven by its own separate control system, i.e., there is no single central process for force or timing (Yamanishi, Kawato & Suzuki, 1980; Wing, Church & Gentner, 1989). On the hypothesis that control may be hierarchical for simultaneous responding and distributed otherwise, experiments will be conducted to determine whether, with training, control can be moved between the two modes; this can be accomplished by starting with simultaneous responding and introducing small amounts of asynchrony, either by instruction or by varying effector combinations, for example between hand and foot. The proportion of common variation of within-hand time or force measures will be taken as an index of the degree of hierarchical control.

A2.2 Ensemble timing (Wing, Nimmo-Smith; Collaborators: Woodburn, Vorberg):

A concrete example of distributed control is ensemble performance in rowing. Individual crew members are clearly capable of making independent strokes; to achieve the observed similarity in force and timing of their movements, there must be transfer of information between rowers. Models for ensemble timing will be developed which should provide a useful base for understanding within-individual coordination between limbs. An important component of the work will be the development of analytic tools for characterising short- and long-term fluctuations in performance within and between individuals. The performance of rowing eights of various levels of expertise will be recorded with the goal of determining the balance between the use of local information (e.g. to maintain relative phase with the rower in front), global information (e.g. to maintain relative phase with motion of the shell) and prediction (e.g. using the verbal cue provided by the cox on the required stroke rate to generate a target interval on the basis of past experience). A further issue that will be investigated is how individuals resolve the competing demands of minimising interstroke interval variance or minimising synchronisation variance.

A2.3 MRI and rhythm production (Wing; Collaborator: Hall):

In single-effector timing, the central-peripheral distinction has been successfully applied in neuropsychological studies of timing deficits in patients with motor disorders. Thus, Ivry, Keele and Dienes (1988) have argued that circuitry underlying central timing processes involves the cerebellum, but not the basal ganglia or motor cortex. To test further the idea that timing is a cerebellar function, an fMRI study will be performed at the Addenbrooke's Hospital facility with normal volunteers, to determine whether there is altered patterning of activity in the cerebellum when repetitive (unilateral) movements must be accurately timed with equal intervals. The contrast of interest will be with similar movements produced in reaction to randomly timed external stimuli at the same overall rate. If this is successful, a further fMRI experiment will seek to contrast simple repetitive timing of a single interval with the production of a rhythmic pattern. Luria's (1966) work on rhythm deficits after stroke suggests that the patterning of time in complex rhythmic tasks is a function of the left frontal cortex. If so, rhythm production in normals should reveal heightened localised cortical activity in that area in addition to elevated activity of the cerebellum as seen in equal interval tapping. Again it will be important to control the overall rates of responding for comparability of baseline metabolic activity levels.

B. Reaching

B3. Two-handed Cooperation (Sellen, Wing, Bishop; Collaborator: Buxton):

Various theoretical accounts of one-handed positioning movements have been proposed (e.g. Meyer et al., 1990) but little is known about how the models apply to two-handed action. Interference is known to occur between simultaneous hand movements with independence as the task goal (e.g. Kelso, Putnam & Goodman, 1984) but the interesting issue of how the two hands are controlled in cooperative action has not been studied systematically. Sellen, Wing and Bishop propose to document such movements, with particular interest in laterality effects. Building on the anecdotal observations of Guiard (1987), two-handed action in selected naturalistic tasks (e.g. picking up and sorting scattered playing cards by suit, opening and closing containers, assembling Lego building blocks) will be videotaped. A detailed, descriptive analysis of the action of each hand in relation to the other will focus on sharing of stabilisation and manipulation aspects of movement. To gain quantitative insight in the mutual dependence of the two hands, Watsmart will be used to record two-handed picking up of various types of objects between the flat palms. Of interest will be the relative guidance of left and right hands (defining a notional grasp shape in approach) under various levels of difficulty and visual constraint.

Practitioners in the human-computer interaction community are beginning to take a keen interest in two-handed interaction techniques, and Sellen will also investigate the kinds of interactions that might be redesigned for two hands. In a study which examined non-preferred hand performance in a one-handed aiming task, Kabbash, Mackenzie and Buxton (1993) found that performance was faster and more accurate with a mouse compared to a trackball. However, in a pilot study that involved asymmetric, dependent action of both hands, Sellen has found that the speed and accuracy of the non-preferred hand is unaffected by device (trackball or mouse) even though it was performing the same aiming movements as in the one-handed case. Sellen plans to pursue this finding in a more complete experiment, comparing performance of the left hand in one- and two-handed tasks. If factors such as device make a difference in the one-handed task, but not in the two-handed task, this will suggest that the subject's conceptualisation of the task can have significant effects on the articulation of the action.

C. Interception *(Tresilian)*

The derivation of alternative models, plus simulation studies designed to determine how best to distinguish the models empirically, will continue to be an important part of Tresilian's study of interception tasks. Various models for braking and catching have already been put forward and it has been shown how these alternatives can all account for existing empirical data. Simulation studies of these models have revealed how various control schemes behave and have also revealed that some control schemes are more desirable than others due to their insensitivity to noise and variation in dynamic parameters. It is proposed to follow up the theoretical papers with empirical work to distinguish between the various models.

D. Grasping

D1. Anticipatory Modulation of Grip Force (Wing, Tresilian; Collaborator: Flanagan):

Previous APU research has demonstrated a robust linkage between increases in grip force and increases in inertial load force during rapid movements of an object held in the hand with a precision grip. Because of their early onset, the grip force adjustments may be identified as anticipatory. What is the basis for this anticipatory organisation? Familiarity with the object's mass and frictional characteristics as a result of slips (which can be identified from the acceleration trace) on previous trials is probably not the answer, since anticipatory grip force modulation is typically seen on the very first trial. Another possibility is that subjects sense the mass in the initial hold phase of the trial, from which they can then compute an expected load force given any chosen acceleration. Given that they are also able to assess surface friction, they may then modulate grip force appropriately.

In a study of the basis of these anticipatory processes, subjects will be asked to move 'virtual' objects endowed with contrasting dynamic properties. The manipulandum will be mounted on a 2-axis force-servoed linear motor system newly-developed at the APU. The system is like a large x-y pen plotter, but it allows any desired force field (e.g. a spring load in which restoring force increases with distance from an equilibrium position) to be defined by computer. The issue is then how grip force modulates over successive trials as subjects learn the dynamics associated with any particular virtual object. Changes in anticipatory grip-force modulation may also be accompanied by changes in the responsiveness of reflexes that can provide recovery of stability if a slip should unexpectedly occur. This possibility will be evaluated by introducing occasional unexpected momentary obstructions to movement while recording surface EMG from the muscles contributing to grip force.

D2. Sensory Factors in Grasp (Wing, Carlyon; Collaborator: Lederman):

The skin on the pads of the fingers and palm of the hand is endowed with numerous sensory receptors which vary both in their rate of adaptation and in the size of their receptive fields (Johannson & Westling, 1990). The properties of these receptors have been charted out with traditional psychophysical procedures adopted from audition, with appropriate change of frequency scale. Their activity has also been demonstrated during functional movement and they have been implicated in the reflex control of grip force to prevent an object slipping from grasp. However, little is known about sensation of a grasped object during voluntary movement. By analogy with saccadic suppression, cutaneous sensory thresholds might be expected to rise during movement. Yet this is just the time when slip information might be needed for reflex support of anticipatory grip adjustments. Wing and Carlyon, in collaboration with Lederman, propose to evaluate sensitivity to vibration of a grasped object during voluntary movement. Testing will include both monitoring of the activity of muscles subserving grasp, and forced-choice verbal report in order to test for dissociation between the effects of movement on grip force and the ability to detect which of two sequential observation periods contained the vibratory signal. If such a dissociation were obtained, it would extend Milner and Goodale (1993) important distinction between vision processing for conscious report versus action into the haptic domain.

D3. Proximal and Distal Anticipatory Postural Adjustments:

Psychologists studying control of movement often distinguish between fine motor skills such as writing, which involve distal musculature (usually of the hand), and gross motor skills such as kicking a ball, which involve musculature of the whole body. However, certain similarities in task definition suggest that this distinction is somewhat contrived. Thus, the role of the digits in modulating grip force to stabilise an object that is subject to external or self-induced loads has functional parallels with action of the legs and trunk that serves to maintain stable upright posture in the face of forces imposed by the environment or by one's own movements.

D3.1 Normal (Wing, Nimmo-Smith; Collaborators: Flanagan, Richardson):

While holding an instrumented load cell in the hand and standing with the feet on separate force plates, subjects will be asked to move the arm rapidly so that the temporal correspondence between grip force adjustment and whole body postural adjustments (as measured by the ground reaction forces) can be examined on a trial by trial basis. Watsmart will be used to track segmental motions. Surface EMG will further document the extent to which there is a correlation between adjustments which would imply common control principles, or even a common controller. Other conditions to explore this possibility will include: (i) jumping on the spot while holding the load cell in fixed position relative to the body, producing contrasting loads on take-off and landing; (ii) using the load cell to push against a fixed support to disturb balance; and (iii) pressing a button to trigger a force that pushes on the load cell and destabilises grasp and standing balance. An important element of this work will be the development of biomechanical models for the forward dynamics, which show how forces at individual joints contribute to observed forces at the end-effector.

D3.2 Changes in cerebellar and Parkinson's disease (Wing; Collaborator: Sagar):

If there are correspondences in the control of stability of grasp and standing balance in normals, it is possible that there is a common underlying process. One likely candidate for such an anticipatory coordination mechanism is the cerebellum, incoordination of upper and lower limb (ataxia) being a 'classic' cerebellar sign. Cerebellar patients will be studied for evidence of breakdown in coordination in anticipatory postural adjustments and grip force adjustments for rapid voluntary arm movements. Comparisons will be made with Parkinson's patients, whose impairment of postural and grip force responses is expected to be restricted to unexpected external perturbations, while their anticipatory adjustments will appear relatively unaffected.

E. Standing Balance

E1. Weight Distribution

E1.2 Balance in the elderly (Maylor, Allison, Wing; Collaborators: Quinn, Simpson):

The explanation suggested for age-related increases in interference between maintaining postural stability and performing cognitive tasks is that cognitive processing resources may be taken by standing balance. Further work is necessary to understand the pattern of effects observed across the different indices of postural stability obtained from SwayWeigh. For example, some cognitive tasks appear to increase random variation (wobble), while others cause a slow drift in weight distribution. To explore the microstructure of such task effects on stability, a reaction time procedure has been developed and pilot experiments performed. This procedure allows the investigation of random and systematic effects of stimulus processing on sway during the response period. Cognitive task performance may also be analysed as a function of the sway recording. Three lines of research will be explored with this paradigm. First, interference effects will be sought in younger subjects exposed to standing under more difficult conditions, such as eyes closed. Second, cognitive task demands will be manipulated by changing the content (e.g. spatial vs. verbal materials) and varying the speed requirements. Third, the possibility of voluntarily allocating resources differentially across the two tasks will be examined, as this will have important implications for training programmes designed to reduce falls in the elderly.

E2. Standing Balance after Stroke

E2.1 Neurophysiological changes and physical therapy (Wing; Collaborators: Jenner, Kirker; supported by Stroke Association):

Hemiparesis often renders stroke patients impaired in their ability to transfer body weight to or from the affected leg. This results in a risk of falling while standing when exposed to forces that may be external in origin or arise from self-initiated actions (including the initiation of gait). The technique developed at the APU of introducing horizontal forces at the hips will be used to evaluate the neurophysiological organisation of balance responses after stroke. Of particular interest will be coordination of the hip abductors and adductors. Pilot studies with a stroke patient many years post-insult have shown reorganisation of these bilaterally arranged muscles such that the non-affected side adductor takes over the function of the affected side abductor. If confirmed in other patients, this will have implications for the retraining of balance. The research will use behavioural and surface EMG responses to document short-term (acquisition) and long-term (retention) effects of training on stability for both expected (self-triggered) and unexpected perturbations. Transfer of training to walking will be evaluated in terms of executing a single step forward, since this requires anticipatory postural adjustments under voluntary control to effect the transition from stable standing to dynamic balance.

E2.2. Assessment of the 'pusher' syndrome (Goodrich; Collaborator: Ashburn):

In the majority of cases, stroke patients compensate for their balance difficulties by shifting their weight onto the ipsilesional (non-paretic) limb. However, in a few cases, patients express fear when encouraged to stand with their weight evenly distributed or predominantly on the non-paretic limb and insist on 'pushing' onto their paretic limb, frequently with disastrous consequences. In the clinical domain, these people are informally defined as 'pushers' and recognised as poor rehabilitation prospects. An assessment procedure has been devised whereby these patients can be distinguished from patients with other balance problems. Work will continue on establishing the reliability and validity of this assessment procedure and factors underlying this syndrome will be explored.

E2.3 Procedural learning after brain damage (Robertson, Wing):

Stroke is a complex disorder and it is likely that patients' limitations in taking benefit from biofeedback in relearning balance skills will reflect not only the hemiparesis but also central decision making and sensory factors. Robertson and Wing therefore propose to study procedural learning of simple skills with the non-affected side. This will allow investigation of the effects of training schedules, frequency and immediacy of knowledge-of-results on learning. Retention and transfer will also be assessed. It is also proposed to evaluate factors, such as verbal distraction during acquisition, which are likely to impede learning and which are often poorly controlled in hospital rehabilitation settings.

PUBLICATIONS *(Excluding work done prior to arrival at APU)*

Authored Books

1.1. WILKINS, A.J. (in press). Visual Stress. Oxford: Oxford University Press.

Edited Books

1.2. Wann, J., WING, A.M. & Søvik, N. (Eds.). (1991). Development of Graphic Skills: Research, Perspectives and Educational Implications. London: Academic Press.

Refereed Articles

1.3. Chen, E.Y.H., WILKINS, A.J. & McKenna, P.J. (1994). Semantic memory is both impaired and anomalous in schizophrenia. Psychological Medicine, 24, 193-202.

1.4. CHRONICLE, E. & NIMMO-SMITH, I. (1992). Application of some statistical methods for comparing samples of hue-angle data. Color Research and Application, 17, 375-378.

1.5. CHRONICLE, E.P. & WILKINS, A.J. (1991). Colour and visual discomfort in migraineurs. The Lancet, 338, p. 890.

1.6. Flanagan, J.R & TRESILIAN, J. (in press). Grip-load force coupling: A general control strategy for transporting objects. Journal of Experimental Psychology: Human Perception and Performance.

1.7. Flanagan, J.R., TRESILIAN, J. & WING, A.M. (1993). Coupling of grip force and load force during arm movements with grasped objects. Neuroscience Letters, 152, 53-56.

1.8. Flanagan, J.R. & WING, A.M. (1993). Modulation of grip force with load force during point-to-point arm movements. Experimental Brain Research, 95, 131-143.

1.9. HAGGARD, P., Jenner, J. & WING, A. (1994). Coordination of aimed movements in a case of unilateral cerebellar damage. Neuropsychologia, 32, 827-846.

1.10. HAGGARD, P. & WING, A.M. (1990). Assessing and reporting the accuracy of position measurements made with optical tracking systems. Journal of Motor Behavior, 22, 315-321.

1.11. HAGGARD, P. & WING, A.M. (1991). Remote responses to perturbation in human prehension. Neuroscience Letters, 122, 103-108.

1.12. Hazell, J. & WILKINS, A.J. (1990). A contribution of fluorescent lighting to agoraphobia. Psychological Medicine, 20, 591-596.

1.13. Henderson, L., Kennard, C., Crawford, T., Day, S., Everett, B., GOODRICH, S., Jones, F. & Park, D.M. (1991). Scales for rating motor impairment in Parkinson's disease: Studies of reliability and convergent validity. Journal of Neurology, Neurosurgery and Psychiatry, 54, 18-24.

1.14. Kasteleijn-Nolst Trenité, D., Dekker, E., Spekreijse, G., Brekelmans, G., WILKINS, A.J. & van Emde Boas,

W. (in press). The role of television, video games and computers in epileptic photosensitive patients: Preliminary results. Epilepsia (Abstract only).

1.15. MacLachlan, A., Yale, S. & WILKINS, A. (1993). Open trial of subjective precision tinting: A follow-up of 55 patients. Ophthalmic and Physiological Optics, 13, 175-178.

1.16. PATTERSON, R.D. (1990). Auditory warning sounds in the work environment. Philosophical Transactions of the Royal Society, B.327, 485-492.

1.17. PATTERSON, R.D. (1990). The tone height of multiharmonic sounds. Music Perception, 8, 203-214.

1.18. PATTERSON, R.D. (in press a). The sound of a sinusoid: Spectral models. Journal of the Acoustical Society of America.

1.19. PATTERSON, R.D. (in press b). The sound of a sinusoid: Time-interval models. Journal of the Acoustical Society of America.

1.20. Smith, A.P., Tyrrell, D.A.J., Barrow, G.I., Higgins, P.G., Bull, S., Trickett, S. & WILKINS, A.J. (1992). The common cold, pattern sensitivity and contrast sensitivity. Psychological Medicine, 22, 487-494.

1.21. Somazzi, L., Della Sala, S. & WILKINS, A.J. (1990). A simple test of contrast sensitivity in glaucoma. Italian Journal of Ophthalmology, 4, 209-213.

1.22. TRESILIAN, J.R. (1993). Four questions of time to contact: A critical examination of research on interceptive timing. Perception, 22, 653-680.

1.23. TRESILIAN, J.R. (1994). Approximate information sources and perceptual variables in interceptive timing. Journal of Experimental Psychology: Human Perception and Performance, 20, 154-173.

1.24. TRESILIAN, J.R. (in press). A note on "Gravity as a monocular cue for perception of distance and/or absolute size. Perception.

1.25. TRESILIAN, J.R. (in press). Perceptual and motor processes in interceptive timing. Human Movement Science.

1.26. Tyrrell, R., Holland, K., Dennis, D. & WILKINS, A.J. (in press). Coloured overlays, visual discomfort, visual search and classroom reading. Journal of Research in Reading.

1.27. Ulrich, R. & WING, A.M. (1991). A recruitment theory of force-time relations in the production of brief force pulses: The parallel force unit model. Psychological Review, 98, 268-294.

1.28. van Galen, G.P., Thomassen, A.J.W.M. & WING, A.M. (1991). Handwriting: A movement theme. Human Movement Science, 10, 163-164.

1.29. van Galen, G.P., Thomassen, A.J.W.M. & WING, A.M. (Eds.). (1991). Handwriting. Human Movement Science (Special Issue), 10. Amsterdam: Elsevier Science Publishers.

1.30. van Vliet, P. & WING, A.M. (1991). A new challenge: Robotics in the rehabilitation of the neurologically motor impaired. Physical Therapy (Special series: Movement Science, Part 2), 71, 39-47.

1.31. Wann, J.P. & NIMMO-SMITH, I. (1990). Evidence against the relative invariance of timing in handwriting. The Quarterly Journal of Experimental Psychology, 42A, 105-119.

1.32. Wann, J. & NIMMO-SMITH, I. (1991). The control of pen pressure in handwriting: A subtle point. Human Movement Science, 10, 223-246.

1.33. WILKINS, A.J. (1991). Visual display units versus visual computation. Behaviour and Information

Technology, 10, 515-523.
1.34. WILKINS, A.J. (1993). Health and efficiency in lighting practice. Energy, 18, 123-129.
1.35. WILKINS, A.J. (1994). Overlays for classroom and optometric use. Ophthalmic and Physiological Optics, 14, 97-99.
1.36. WILKINS, A.J. & CLARK, C. (1990). Modulation of light from fluorescent lamps. Lighting Research and Technology, 22, 103-109.
1.37. WILKINS, A.J., Evans, B., Brown, J., Busby, A., Wingfield, A., JEANES, R. & Bald, J. (1994). Double-blind placebo-controlled trial of precision spectral filters in children who report perceptual distortion. Investigative Ophthalmology and Visual Science, 35, p. 1573.
1.38. WILKINS, A.J., MILROY, R., NIMMO-SMITH, I., Wright, A., Tyrrell, R., Holland, K., Martin, J., Bald, J., Yale, S., Miles, T. and Noakes, T. (1992). Preliminary observations concerning treatment of visual discomfort and associated perceptual distortion. Ophthalmic and Physiological Optics, 12, 257-262.
1.39. WILKINS, A.J. & Neary, C. (1991). Some visual, optometric and perceptual effects of coloured glasses. Ophthalmic and Physiological Optics, 11, 163-171.
1.40. WILKINS, A.J., NIMMO-SMITH, I. & Jansons, J. (1992). Colorimeter for the intuitive manipulation of hue and saturation and its role in the study of perceptual distortion. Ophthalmic and Physiological Optics, 12, 381-385.
1.41. WILKINS, A.J., Peck, A. & Jordan, B. (1991). Visual discomfort in the classroom. Child Language, Teaching and Therapy, 7, 326-340.
1.42. WILKINS, A.J. & Wilkinson, P. (1991). A tint to reduce eye-strain from fluorescent lighting? Preliminary observations. Ophthalmic and Physiological Optics, 11, 172-175.
1.43. WING, A.M. (1992). The uncertain motor system: Perspectives on the variability of movement. In D.E. Meyer & S. Kornblum (Eds.), Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience (pp. 708-744). Cambridge, MA: The MIT Press.
1.44. WING, A.M., BARTON, J., TURTON, A. & Howick, I. (1992). Regulation of lateral position of body centre of mass in standing balance. Physiotherapy Theory and Practice, 8, 131-135.
1.45. WING, A.M., CLAPP, S. & Burgess-Limerick, R. (in press). Standing stability in the frontal plane determined by lateral forces applied to the hip. Gait and Posture.
1.46. WING, A.M., GOODRICH, S., VIRJI-BABUL, N., Jenner, J.R. & CLAPP, S. (1993). Balance evaluation in hemiparetic stroke patients using lateral forces applied to the hip. Archives of Physical Medicine and Rehabilitation, 74, 292-299.
1.47. WING, A.M., Lough, S., TURTON, A., Fraser, C. & Jenner, J.R. (1990). Recovery of elbow function in voluntary positioning of the hand following hemiplegia due to stroke. Journal of Neurology, Neurosurgery and Psychiatry, 53, 126-134.

Submitted

1.48. Flanagan, J.R. & WING, A.M. Grip force in cyclic movments. (Manuscript submitted to Experimental Brain Research).
1.49. Flanagan, J.R., WING, A.M., Allison, S. & Spenceley, A. Effects of surface texture on weight perception

when lifitng objects with a precision grip. (Manuscript submitted to Perception and Psychophysics).

1.50. HAGGARD, P. & WING, A.M. Coordination of hand aperture with the spatial path of hand transport. (Manuscript submitted to Acta Psychologica).

1.51. HAGGARD, P. & WING, A.M. Coordinated responses following mechanical perturbation of the arm during prehension. (Manuscript submitted to Experimental Brain Research).

1.52. MCKEOWN, J.D. & PATTERSON, R.D. The time course of auditory segregation: concurrent vowels that vary in duration. (Manuscript submitted to Journal of the Acoustical Society of America)

1.53. ROBINSON, K. & PATTERSON, R.D. (submitted a) Is pitch required in the extraction of timbre? (Manuscript submitted to Journal of the Acoustical Society of America)

1.54. ROBINSON, K. & PATTERSON, R.D. (submitted b) Is pitch required to extract the timbre of steady-state instruments? (Manuscript submitted to Music Perception)

1.55. TRESILIAN, J.R. (submitted a). Automatic and cognitive processes in time-to-contact estimation: Analysis of the disappearing target paradigm. (Manuscript submitted to Perception and Psychophysics).

1.56. TRESILIAN, J.R. (submitted b) Study of a servo control strategy for projectile interception. (Manscript submitted to Quarterly Journal of Experimental Psychology).

1.57. Ulrich, R. WING, A.M. & Rinkenauer, G. Scaling of brief force impulses. (Manuscript submitted to Journal of Experimental Psychology: Human Perception and Performance).

1.58. WING, A.M & Woodburn, C. Coordination between rowers in a racing eight. (Manuscript submitted to Journal of Sports Sciences).

Invited Chapters and Commentaries

1.59. HAGGARD, P. (1992). Multi-sensory control of coordinated movement. In J. Summers (Ed.), Approaches to the Study of Motor Control and Learning (pp. 195-231). Amsterdam: Elsevier Science Publishers B.V.

1.60. Kennard, C. & WILKINS, A.J. (1993). Special senses. In R.J. Greenwood, M.P. Barnes, T.M. McMillan & C.D. Ward (Eds.), Neurological Rehabilitation (pp. 259-267). Edinburgh: Churchill Livingston.

1.61. PATTERSON, R. (1990). Auditory warning sounds in the work environment. In D.E. Broadbent, A.D. Baddeley & J.T. Reason (Eds.), Human Factors in Hazardous Situations (pp.485-492). Oxford: Clarendon Press. (Phil. Trans. R. Soc. London, B327).

1.62. PATTERSON, R.D. (1990). Listening. Brain, 113, 1245-1246.

1.63. PATTERSON, R.D. & AKEROYD, M. A. (in press). Time-interval patterns and sound quality. In G. Manley, G. Klump, C. Koppl, H. Fastl, & H. Oeckinghaus (Eds.), In Advances in Hearing Research: Proceedings of the 10th International Symposium on Hearing, Singapore: World Scientific.

1.64. PATTERSON, R.D., ALLERHAND, M. & HOLDSWORTH, J.W. (1993). Auditory representations of speech sounds. In M. Cooke & S. Beet (Eds.), Visual Representations of Speech Signals (pp. 307-314). Chichester: John Wiley & Sons.

1.65. PATTERSON, R.D. & HOLDSWORTH, J. (in press). A functional model of neural activity patterns and auditory images. In W.A. Ainsworth (Ed.), Advances in Speech, Hearing and Language Processing, vol. 3. London: JAI Press.

1.66. PATTERSON, R.D., ROBINSON, K., HOLDSWORTH, J., MCKEOWN, D., ZHANG, C. & ALLERHAND, M. (1992). Complex sounds and auditory images. In Y. Cazals, K. Horner & L. Demaney (Eds.), Auditory Physiology and Perception (9th International Symposium on Hearing, 1992) (pp. 429-446), Oxford: Pergamon Press.

1.67. Ulrich, R. & WING, A.M. (1993). Variability in brief force pulses. In K.M. Newell & D.M. Corcos (Eds.), Variability and Motor Control. Champaign, Illinois: Human Kinetics.

1.68. Vorberg, D. & WING, A. (1994). Modelle fur Variabilitat und Abhangigkeit bei der zeitlichen Steuerung. In Enzyklopaedie der Psychologie Gottingen (pp. 223-320). Germany: Hogrefe Verlag fur Psychologie.

1.69. Vorberg, D. & WING, A. (in press). Modeling variability and dependence in timing. In H. Heuer & S.W. Keele (Eds.), Handbook of Perception and Action, Vol. 3: Motor Skills. London: Academic Press.

1.70. WILKINS, A.J. (1990). Stress and distress from fluorescent lighting. In S. Puglisi-Allegra & A. Oliverio (Eds.), Psychobiology of Stress (pp. 211-221). The Netherlands: Kluwer Academic Press.

1.71. WILKINS, A.J. (1991). Visual discomfort and reading. In J.F. Stein (Ed.), Vision and Visual Dyslexia (pp. 155-170). Basingstoke: Macmillan Press.

1.72. WILKINS, A.J. (1993). Reading and visual discomfort. In D.M. Willows, R.S. Kruk & E. Corcos (Eds.), Visual Processes in Reading and Reading Disabilities (pp. 345-356). Hillsdale, N.J.: Lawrence Erlbaum Associates.

1.73. WILKINS, A.J., Binnie, C.D., Darby, C.E. & Kasteleijn-Nolst Trenité, D. (1990). Inferences regarding the visual precipitation of seizures, eye strain, and headaches. In M. Avoli, P. Gloor, G. Kostopoulos & R. Naquet (Eds.), Generalised Epilepsy: Neurological Approaches (pp. 314-326). Boston: Birkhauser.

1.74. WING, A.M. (1990). Coordination in normal and prosthetic reaching. In S.T. Venkataraman & T. Iberall (Eds.), Dextrous Robot Hands (pp.55-65). New York: Springer-Verlag Inc.

1.75. WING, A.M. (1990). Étude de la Variabilité dans la Forme Spatiale de L'Écriture Cursive. In C. Sirat, J. Irigoin & E. Poulle (Eds.), L'Écriture: Le Cerveau, L'Ceil et la Main Bibliologia Vol. 10 (pp.127-137). Turnhout: Brepols.

1.76. WING, A.M., ALLISON, S. & Jenner, J.R. (1993). Retaining and retraining balance after stroke. In C.D. Ward (Ed.), Baillière's Clinical Neurology, Vol. 2: Rehabilitation of Motor Disorders (pp. 87-120). London: Baillière Tindall.

1.77. WING, A.M., WATTS, F. & Sharma, V. (1991). Developmental dynamics of handwriting: Appraising the relation between handwriting and personality. In J. Wann, A. Wing & N. Søvik (Eds.), Development of Graphic Skills: Research, Perspectives and Personal Implications (pp. 164-175). London: Academic Press.

Conference Proceedings

1.78. ALLERHAND, M., BUTTERFIELD, S., CUTLER, A. & PATTERSON, R. (1992). Assessing syllable strength via an auditory model. In Proceedings of the Institute of Acoustics, Vol. 14, part 6 (pp. 297-304).

1.79. ALLERHAND, M. & PATTERSON, R. (1992) Correlograms and auditory images. In Proceedings of the Institute of Acoustics, Vol. 14, part 6, (pp. 281-288).

1.80. Anderson, T. & PATTERSON, R.D. (in press). Speaker recognition with the auditory image model and self-organising feature maps: A comparison with traditional techniques. In Proceedings of ESCA workshop.

Martingy, Switzerland.

1.81. HOLDSWORTH, J., Schwartz, J.L., Berthommier, F. & PATTERSON, R.D. (1992). A multi-representation model for auditory processing of sounds. In Y. Cazals, K. Horner & L. Demaney (Eds.), Auditory Physiology and Perception (Proceedings of the 9th International Symposium on Hearing, 1992) (pp. 447-453). Oxford: Pergamon Press.

1.82. Irino, T & PATTERSON, R.D. (in press). A theory of asymmetric intensity enhancement. in non-simultaneous masking. In Proceedings of the Third ICSLP, Yokohama, Japan.

1.83. Kabbash, P., Buxton, W. & SELLEN, A. (1994). Two-handed input in a compound task. Proceedings of SIGCHI T94 (pp. 417-423). Boston, MA.

1.84. PATTERSON, R.D., Anderson, T. & ALLERHAND, M. (in press). The auditory image model as a preprocessor for spoken language. In Proceedings of the Third ICSLP, Yokohama, Japan.

1.85. PATTERSON, R.D., HOLDSWORTH, J. & ALLERHAND, M. (1992). Auditory models as preprocessors for speech recognition. In M.E.H.. Schouten (Ed.), The Auditory Processing of Speech: From the Auditory Periphery to Words (pp. 67-83). Berlin: Mouton de Gruyter.

1.86. PATTERSON, R.D., MILROY, R. & ALLERHAND, M. (1993). What is the octave of a harmonically rich note? In I. Cross & I. Deliege (Eds.), Music and the Cognitive Sciences 1993. (Proceedings of Cambridge Conference on Music and the Cognitive Sciences 1990) (pp. 69-81). Switzerland: Harwood Academic Publishers.

1.87. ROBINSON, A., HOLDSWORTH, J., PATTERSON, R. & Fallside, F. (1990). A comparison of preprocessors for the Cambridge recurrent-error-propagation-network speech recognition system. In Proceedings of First ICSLP, Kobe, Japan.

1.88. Watt, R.J., Bock, J., Thimbleby, H. & WILKINS, A.J. (1990). Visible aspects of text. In Proceedings of Conference on "Applying Visual Psychophysics to User Interface Design" (pp.309-325), Lavenham, May 1990, organised by British Telecom.

1.89. WILKINS, A.J. (1990). Visual display units versus visual computation. In Proceedings of Conference on "Applying Visual Psychophysics to User Interface Design" (pp. 257-265), (Lavenham, May 1990, organised by British Telecom).

1.90. WILKINS, A.J. (1991). Light right for sight: Health and efficiency in lighting practice. In E. Mills (Ed.), Proceedings of the 1st European Conference on Energy-Efficient Lighting (pp. 57-63). Stockholm: Swedish National Board for Ind. & Technical Development, Department of Energy Efficiency.

1.91. WILKINS, A.J. (1993). Possibilities for migraine therapy using coloured glasses? In T.J. Steiner & L.A.H. Hogenhuis (Eds.), Headache and Migraine (Proceedings of the Anglo-Dutch Migraine Meeting, Canterbury, 1992) (pp. 10-15). Utrecht: Bunge.

1.92. WILKINS, A.J. (1994). Reading and individual preferences for illuminant chromaticity. In Proceedings of Lux Europa (Edinburgh).

1.93. WING, A.M., ALLISON, S., Cooper, N. & Thompson, S. (1992). Cooperative timing on the River Cam. In C. Auxiette, C. Drake & C. Gerard (Eds.), Proceedings of the Fourth Workshop on Rhythm Perception and Production (pp. 85-95) Bourges, France, June 1992.

Technical Reports and Theses

1.94. ALLERHAND, M. & PATTERSON, R.D. (1993). Measurement of stress in speech. AAM HAP Progress Report No. 3, APU Contract Report.

1.95. ALLERHAND, M. & PATTERSON, R.D. (1994). Vocal agitation as a predictor of emotion and stress. AAM HAP Final Report, APU Contract Report.

1.96. ALLERHAND, M. & PATTERSON, R.D. (1994). User documentation for the AIM software package. AAM HAP Progress Report No. 5, APU Contract Report.

1.97. ALLERHAND, M., PATTERSON, R.D., ROBINSON, K. & Rice, P. (1990). Optimisation of the SVOS algorithm. SVOS Progress Report No. 4, APU Contract Report.

1.98. ALLERHAND, M., PATTERSON, R.D., ROBINSON, K. & Rice, P. (1991). Application of the SVOS algorithm. SVOS Progress Report No. 5, APU Contract Report.

1.99. CHRONICLE, E. (1993). Visual discomfort and visual dysfunction in migraine. Unpublished PhD Thesis, University of Cambridge.

1.100. HAGGARD, P. (1991). The coordination of human prehension. Unpublished PhD Thesis, University of Cambridge.

1.101. Irino, T & PATTERSON, R.D. (1994a) A computational theory of asymmetric intensity enhancement. around acoustic transients. Technical Report: ISRL-93-9, NTT , Japan.

1.102. Lower, M.C. & PATTERSON, R.D. (1991). Spectrum modification of the PWID output between free-field and at-the-ear measurements. Institute of Sound and Vibration Report No. AC693/4.

1.103. Lower, M.C. & PATTERSON, R.D. (1992). Acoustical specifications and test procedures for the British Rail ILWS PWID. Institute of Sound and Vibration Research, Report No. AC 693/6, May.

1.104. Lower, M.C. & PATTERSON, R.D. (1992). Implementation of warning sounds in the British Rail 'ILWS' prototype. Institute of Sound and Vibration Research, Report No. AC 693/5, May.

1.105. Lower, M.C. & PATTERSON, R.D. (in press). Acoustical measurements on PWID prototype A09. Institute of Sound and Vibration Report No. AC693/5.

1.106. Lower, M.C., PATTERSON, R.D., Patten, I.T. & MILROY, R. (1991). Design and installation of a sound system to aid passenger evacuation from aircraft. Institute of Sound and Vibration Research Report No. AC684/1.

1.107. PATTERSON, R., ALLERHAND, M. & AKEROYD, M. (1993). AAM HAP Progress Report No. 4, August 1993. MOD 3207 Contract Report.

1.108. PATTERSON, R.D. & DATTA J (1994). Extending the frequency range of existing warning sounds. AAM HAP Auditory Warnings: Progress Report No. 1, APU Contract Report..

1.109. PATTERSON, R.D. & HOLDSWORTH, J. (1990). An introduction to auditory sensation processing. AAM HAP Progress Report No. 1, APU Contract Report.

1.110. PATTERSON, R., NORRIS, D., & CUTLER, A. (Eds.) (1990). Auditory/Connectionist Techniques for Speech (ACTS) Periodic Progress Report No. 1, and associated Annexe. CEC: Brussels, June 1990.

1.111. PATTERSON, R.D., NORRIS, D. & CUTLER, A. (Eds.) (1991). Auditory/Connectionist Techniques for Speech. (ACTS) Periodic Progress Report No. 2 and associated Annexes. Brussels: CEC.

1.112. PATTERSON, R.D., NORRIS, D. & CUTLER, A. (1992). Auditory/Connectionist Techniques for Speech.

(ACTS) Periodic Progress Report No, 3. Brussels: CEC, July.
1.113. ROBINSON, K. (1993). Studies in timbre and pitch. Unpublished PhD Thesis, University of Cambridge.
1.114. WILKINS, A.J. (1992). Colour Control: A Computer Program to check the Chromaticity of Lenses and Issue Guidance for their Use. Applied Psychology Unit.
1.115. WILKINS, A.J. (1992). Information about Televisions and Computer Displays for Patients with Photosensitive Epilepsy. The British Epilepsy Association.
1.116. WILKINS, A.J. (1993). A System for Precision Ophthalmic Tinting: Manual for the Intuitive Colorimeter. Cerium Visual Technologies, 27 pp.
1.117. WILKINS, A.J. (1993). Intuitive Overlays for Use by Teachers and Optometrists. Institute of Optometry Marketing.
1.118. WILKINS, A.J. (1993). Photosensitive Epilepsy Associated with Playing Computer Games. Report commissioned by the Department of Trade and Industry, 34 pp.
Tests and Patents
1.119. HOLDSWORTH, J.W. & PATTERSON, R.D. (1991). Analysis of waveforms. UK Patent No. GB 2-234-078-A (23.1.91). London: UK Patent Office.
1.120. PATTERSON, R.D. & HOLDSWORTH, J.W. (1990). Apparatus and methods for the generation of stabilised images from waveforms. World Intellectual Property Organization, WO 90/14656 (29 November 1990), 1990.
1.121. WILKINS, A.J. (1994). Apparatus for and a Method of Obtaining an Ophthalmic Tint. UK Patent No. 2,246,427 (4th May 1994). London: UK Patent Office.
1.122. Wilkinson, P.R. & WILKINS, A.J. (1991). Optical Devices for Reducing Photophobia. Patent No. GB 9000165 (4.1.91). London: UK Patent Office.
1.123. WING, A.M. & BARTON, J. (1992). SwayWeigh UK Patent App No 9212845.3 Filing date: 17/6/92 by MRC for Analogue balance.

REFERENCES TO OTHER WORK

Assmann, P. & Summerfield, Q. (1990). Modeling the perception of concurrent vowels: Vowels with different fundamental frequencies. Journal of the Acoustical Society of America, 88, 680-697.
Assmann, P. & Summerfield, Q. (1994). The contribution of waveform interactions to the perception of concurrent vowels. Journal of the Acoustical Society of America, 95, 471-484.
Assmann, P. & Summerfield, Q. (1989). Modeling the perception of concurrent vowels: Vowels with the same fundamental frequency. Journal of the Acoustical Society of America, 85, 327-338.
Carlyon, R.P. (1991). Discriminating between coherent and incoherent frequency modulation of complex tones. Journal of the Acoustical Society of America, 89, 329-340.
Carlyon, R.P. (1994a). Detecting pitch-pulse asynchronies and differences in fundamental frequency. Journal of the Acoustical Society of America, 95, 968-979.
Carlyon, R.P. (1994b). Further evidence against an across-frequency mechanism specific to the detection of FM incoherence between resolved frequency components. Journal of the Acoustical Society of America, 95, 949-

961.
Carlyon, R.P., Demany, L. & Semal, C. (1992). Detection of across-frequency differences in fundamental frequency. Journal of the Acoustical Society of America, 91, 279-292.
Carlyon, R.P. & Shackleton, T.M. (in press). Comparing the fundamental frequencies of resolved and unresolved harmonics: Evidence for two pitch mechanisms? Journal of the Acoustical Society of America.
Chapman, S. (1968). Catching a baseball. American Journal of Physics, 36, 868-870.
Ciocca, V. & Bregman, A.S. (1987). Perceived continuity of gliding and steady-state tones through interrupting noise. Perception and Psychophysics, 42, 476-484.
Dienes, Z. & McLeod, P. (1993). How to catch a cricket ball. Perception, 22, 1427-1439.
Guiard, Y. (1987). Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model. Journal of Motor Behavior, 19, 486-517.
Hartmann, W.M., McAdams, S. & Smith, B.K. (1990). Hearing a mistuned harmonic in an otherwise periodic complex tone. Journal of the Acoustical Society of America, 88, 1712-1724.
Ivry, R.B., Keele, S.W. & Diener, H.C. (1988). Dissociation of the lateral and medial cerebellum in movement timing and movement execution. Experimental Brain Research, 73, 167-180.
Johannson, R.S. & Westling, G. (1990). Tactile afferent signals in the control of precision grip. In M. Jeannerod (Ed.), Attention and Performance XIII: Motor Representation and Control. Hillsdale, N.J.: Lawrence Erlbaum Associates.
Kabbash, P., MacKenzie, I.S. & Buxton, W. (1993). Human performance using computer input devices in the preferred and non-preferred hands. In Proceedings of InterCHI '93 (pp. 474-481).
Kelso, J.A. S., Putnam, C.A. & Goodman, D. (1983). On the space-time structure of human interlimb coordination. Quarterly Journal of Experimental Psychology, 35A, 347-375.
Lee, D.N. (1976). A theory of visual control of braking based on information about time to collision. Perception, 5, 437-459.
Lee, D.N., Reddish, P.E. & Rand, D. (1991). Aerial docking by hummingbirds. Naturwissenschaften, 78, 526-527.
Luria, A.R. (1966). Higher Cortical Functions in Man. London: Tavistock.
Massaro, D.W. (1975). Backward recognition masking. Journal of the Acoustical Society of America, 58, 1059-1065.
Meddis, R. & Hewitt, M. (1991). Virtual pitch and phase sensitivity studied using a computer model of the auditory periphery: Pitch identification. Journal of the Acoustical Society of America, 89, 2866-2882.
Meyer, D.E., Keith Smith, J.E., Kornblum, S., Abrams, R.A. & Wright, C.E. (1990). Speed-accuracy tradeoffs in aimed movements: Toward a theory of rapid voluntary action. In M. Jeannerod (Ed.), Attention and Performance XIII: Motor Representation and Control. Hillsdale, N.J.: Lawrence Erlbaum Associates.
Milner, A.D. & Goodale, M.A. (1993). Visual pathways to perception and action. In T.P. Hicks, S. Molotchnikoff & T. Ono (Eds.), Progress in Brain Research. Amsterdam: Elsevier.Tresilian, J.R. (1991). Empirical and theoretical issues in the perception of time to contact. Journal of Experimental Psychology: Human Perception & Performance, 17, 865-876.

Moore, B.C.J. & Ohgushi, K. (1993). Audibility of partials in inharmonic complex tones. Journal of the Acoustical Society of America, 93, 452-461.

Patterson, R.D. & Hirahara, T (1989). HMM speech recognition using DFT and auditory spectrograms. ATR Technical Report, Kyoto, Japan.

Scheffers, M.T.M. (1983). Sifting vowels: Auditory pitch analysis and sound segregation. Doctoral dissertation, University of Groningen, Netherlands.

Slaney, M. & Lyon, R.F. (1990). A perceptual pitch detector. In Proceedings of the International Conference on Acoustics, Speech, and Signal Processing (pp. 357-360).

Vorberg, D. & Hambuch, R. (1984). Timing of two-handed rhythmic performance. In J. Gibbon & L. Allan (Eds.), Timing and Time Perception. Annals of the NY Academy of Sciences, 423, 390-406.

Westling G & Johansson R.S. (1984). Factors influencing the force control during precision grip. Experimental Brain Research, 53, 277-284

Wilkins, A.J., Nimmo-Smith, I., Slater, A.I. & Bedocs, L. (1989). Fluorescent lighting, headaches and eyestrain. Lighting Research and Technology, 21, 11-18. (Revised version of APU 2279)

Wing, A. (1988). A comparison of the rate of pinch grip force increases and decreases in Parkinsonian Bradykinesia. Neuropsychologia, 26, 479-482.

Wing, A.M., Church, R.M. & Gentner, D.R. (1989). Variability in the timing of responses during repetitive tapping with alternate hands. Psychological Research, 51, 28-37.

Yamanishi, J., Kawato, M. & Suzuki, R. (1980). Two coupled oscillators as a model for the coordinated finger tapping by both hands. Biological Cybernetics, 37, 219-225.

Collaborations

Carlyon

Outside UK

Demany, Semal - Psychoacoustics, Bordeaux

Maylor

UK based

Quinn - Psychology, St Andrews

Simpson - Geriatrics, St George's Hospital, London

Patterson, R

UK based

Rood - Defence Research Agency, Farnborough

Fallside, Giguerre - Engineering, Cambridge

Moore, Baer - Psychology, Cambridge

Robinson - Institute of Hearing Research, Glasgow

Outside UK

Anderson, Gilkey - Wright-Patterson Air Force Base, Ohio

Yost, Fay - Parmley Hearing Institute, Chicago

Feth, Krishnamurthy - Speech and Engineering, Ohio State

Blauert, Bodden - Engineering Bochum

Berthomier, Schwartz - Institute Communication de Parole, Grenoble

Kawahara, Tokura - Advanced Telephonic Research, Kyoto

Sellen

Outside UK

Buxton - Computer Science, Toronto

Wilkins

UK based

Brown - David Lewis Centre for Epilepsy, Cheshire

Evans - Institute of Optometry, London

Fish - National Hospital, London

Kennard - Neurology, Charing Cross Hospital, London

Martin - William Westley CP School, Cambridge

Smith, Troscianko - Psychology, Bristol

Smith - Psychology, Bradford

Outside UK

Kasteleijn - Instituut voor Epilepsiebestreijding, Netherlands

Jaen - University of Tukaman

Wing

UK based

Burgess-Limerick, Clapp, Howick, Jenner, Kirker - Rehabilitation, Cambridge

Fraser, Turton - Occupational Therapy, Cambridge

Sagar - Neurology, Sheffield

van Vliet - Stroke Research, Nottingham

Virji-Babul - Physiotherapy, Cambridge

Woodburn - Engineering, Cambridge

Outside UK

Bisiacchi - Psychology, Padova

Flanagan - Movement Science, Columbia, NY

Lederman - Psychology, Kingston, Ontario

Richardson, Biomechanics, Orsay, Paris

Ulrich - Psychology, Konstanz

Vorberg - Psychology, Braunschweig

ATTENTION AND COGNITIVE CONTROL

Barnard 4.25, Blandford 2.92, Brown 4.58, Chapman 4.42, Duncan 5.0, Emslie 3.92, Godden 0.67, Goodrich 3.50, Groeger 4.42, Howes 5.0, Lavie 1.0, Marcel 5.0, May 2.25, Nimmo-Smith 1.0, Sellen 0.73, Shallice 1.0, Ward 2.9, Whittington 2.58, Wilkinson 1.0, R Young 5.0, Allison (SO) 1.0, Bright (SO) 0.37, Clegg (SO) 1.58, Duff (SO) 0.34, Gourdol (CO) 0.17, Grande (SO) 3.5, A Green (SO) 2.08, P Houghton (Student) 0.21, van Houten (SO) 0.16, Kolodny (SO) 0.75, Newell (SO) 0.42, Robinson (SO) 0.18, Salber (SO) 0.17, Scott (SO) 0.85, Taylor (SO) 0.08, Tweedie (SO) 1.25.

Total Person Years: Scientists 61.1; Research Support 13.1

Abstract

Objectives

In this programme we investigate the coordination of cognitive activity. Even a simple cognitive event, such as directing attention to a relevant object in the visual world, requires coordinated activity in multiple brain systems. The problem is brought even more to the fore in tasks of realistic complexity, such as learning a novel computer system or controlling a vehicle through traffic. Our strategy is to investigate examples at multiple levels of complexity. The approach is broadly multidisciplinary: for simple cases, the approach combines cognitive psychology and basic neurobiology; in more complex cases, there is major input from artificial intelligence and computer science. We seek to understand basic processes of attention, intelligence, acquisition and use of knowledge, and consciousness.

Scientific progress and achievements over the past five years

Good progress has been made towards a cognitive-neurobiological model of selective attention in vision. This case provides a simple, concrete example of the general problem of coordination. According to the model, attention develops as an emergent state in which multiple brain systems work concurrently on the same object. Collaborative projects have allowed tests of the model in single unit recording from the macaque, and in studies of brain lesions, regional cerebral activation and normal behaviour in the human. Clinical applications are also beginning through collaborative work with the programme addressing rehabilitation of unilateral neglect.

At the next level of complexity are studies of executive functions, intelligence and consciousness. Cognitive and neuropsychological studies suggest a central role for frontal lobe functions, in particular goal management and selection, in traditionally-defined intelligence. Our studies of consciousness have dealt especially with visual, spatial and bodily awareness. Dissociations of consciousness have been demonstrated through

neuropsychological studies of mode of report, cueing conditions for action, and awareness of deficit. Again a key question is how dissociable systems combine to produce unitary behavioural phenomena such as goal selection and awareness.

Besides their immediate practical application, studies of real-world tasks allow us to consider the full problem of cognitive models sufficiently powerful and integrated to explain real behaviour. We have worked with models such as Soar, a general architecture for integrated control of cognition, and Barnard's Interacting Cognitive Subsystems, in which content-specific cognitive modules combine to produce coherent behaviour. Continuing our strong tradition in the field, a major test bed for such approaches has been human-computer interaction (HCI), supplemented by studies of driving and of action slips by anaesthetists. Our studies have shown contrasts between multiple forms of learning and knowledge, including instructed and exploratory learning in both HCI and driving, people's knowledge of their own proficiency, and action slips from familiar automatisms in the setting of anaesthesia.

Future plans for the next five years

The joint cognitive-neurobiological approach to visual attention, frontal lobe functions, intelligence and consciousness will be extended over the next five years. Behavioural studies will address the conditions, time-course and nature of multiple forms of competition between candidate cognitive activities, the limits of voluntary control, and the contribution of executive functions to intelligence. In the area of consciousness, a major emphasis will be on bodily sensation, including studies of deafferentation, body image and pain, including pain under general anaesthetic. These cognitive studies provide the basis for studies of neural implementation. Through collaborations in Cambridge and elsewhere, we have a developing programme in functional brain imaging. As one example, we shall investigate the role of frontal functions in various tests of general intelligence. We are also developing (i) a panel of patients with well-characterized, focal brain lesions for joint behavioural and functional activation work; (ii) our collaborations on rehabilitation after stroke and head injury; and (iii) our collaborations on single cell electrophysiology. Our aim is to give the APU a central role in a multidisciplinary team addressing the neurobiology of well-specified higher cognitive functions.

With the departure of Brown and Groeger, the APU's distinguished 40-year programme of research in driver behaviour has come to an end. This makes the HCI work even more central to our study of cognition in tasks of realistic complexity. New topics to be addressed include the structuring and selection of dynamic visual input, control of behaviour by input from the device being utilized, and the development of formalisms for communication between experts in cognitive psychology, AI and design. The topics of complex visual selection, goal representation and action choice are all points of contact with the more basic, neurobiological parts of the Attention and Cognitive Control programme. By moving between simpler and more complex cases, we hope to maintain the balance of tractability and applicability to real behaviour.

Implications for improving health, health care and wealth creation

The tremendous economic significance of both driving and HCI research hardly needs stating. On British roads there are around 70,000 serious injuries each year; the European research to which we have contributed, dealing with development of new driving technology, has potential application to hundreds of millions of vehicles. As witnessed for example by the overwhelming success of icon-based systems, development of usable computer interfaces now has direct impact on almost every field of activity in industrialized countries. In our work we have given explicit attention to the problem of moving from scientific analysis to real device design. In 1991, Brown's distinguished contributions to British driver safety were recognised by award of the OBE.

Our neurobiological work too has increasing clinical and economic significance. Disabling executive impairments are common, for example, following closed head injury. The most common victims of head injury are young men at the start of their work lives. Attentional impairments, especially unilateral neglect, are also a common consequence of strokes and other brain insults. Management of these conditions is now the subject of active collaboration with the Neuropsychological Rehabilitation team.

INTEGRATED COMPETITION IN DISTRIBUTED BRAIN SYSTEMS *(Duncan, Emslie, Houghton, Ward)*

Introduction

A major theme guiding research into attention is control of behaviour by competition. One perceptual input, action or line of processing gains precedence at the expense of others. Different forms of competition are reflected, for example, in different sources of interference between concurrent tasks.

Two different aspects of competition are emphasised here. The first and best developed concerns vision: At any given time, we have detailed awareness of only a few objects in the visual field, the remainder being disregarded or ignored. Experiments are concerned especially with interference between one part of the visual input and another. A second project concerns relationships between frontal lobe functions, individual differences in general intelligence or Spearman's g, and interference between tasks sharing little in the way of input modality, output modality or common content. We relate these problems to competition between concurrent action requirements or goals.

A second major theme is integration between brain systems. Multiple brain systems are involved in the competitive control of even simple behaviour. As well as defining their separate roles, we must understand how systems are integrated to work concurrently on the same object or task.

Over the past 5 years the work of this group has become increasingly interdisciplinary. As the central element, we have continued to develop functional models from research on normal human cognition. Within the APU, we have begun to work closely with Robertson's group on the consequences of attentional models for clinical practice and rehabilitation (this work is described largely in Robertson's section of the report, in the Rehabilitation programme; see also the related proposals by Goodrich in this programme). At the same time, we have turned, through a series of outside collaborations, to investigations of how attentional functions are implemented in the human and animal brain. Single unit recording in awake monkeys has allowed us to study attentional modulation of neural responses at different levels of the visual system. To initiate this project, Duncan spent the year 1989-90 working with Robert Desimone at NIMH in Bethesda; the work has since developed with grant support from the U.S. Office of Naval Research and the Human Frontier Science Program. The latter grant has also allowed collaborations with groups working on human lesion studies (Glyn

Humphreys, Birmingham), functional activation using PET (Guy Orban, Leuven), and modelling (Claus Bundesen, Copenhagen).

A. Visual Attention *(Duncan, Ward)*

In the last Progress Report, we outlined a general account of the functions involved in visual selective attention (2.25, 2.26, 2.95). At any given time, objects in the visual field compete for representation in visual short-term memory. Subjectively, this competition is reflected in limited attentional capacity. Competition introduces the problem of selectivity: we attend to objects that are relevant to current behaviour, and ignore the remainder. To bias competition towards relevant objects, candidate objects in the visual input are compared against a flexible attentional template, or advance description of information currently required (2.26, 2.95). According to the task, this template can specify many different object properties, including location, motion, object features etc. Objects matching the template gain a competitive advantage, and are more likely to be selected for control of behaviour. The model has been applied to a range of problems, including selective and divided attention (2.95), visual search and visual grouping (2.25, 2.26).

In the present reporting period, the model has been developed through a series of further studies, both behavioural and physiological:

1. One set of behavioural studies has dealt with the role of objects in attentional competition. When concurrent discriminations concern different objects, competition results in reduced accuracy. When discriminations concern different attributes of the same object, however, all interference disappears (2.22). This general conclusion holds true even for attributes such as colour and motion, whose processing is separated into quite distinct cortical systems (2.21, 2.95). The implication is that, when an object is selected for control of behaviour, all of its attributes are selected together.

A second set of behavioural studies has dealt with the time-course of attentional competition. Conventional serial models suggest that each object consumes processing capacity for only a few dozen msec; in contrast, our single cell results (see below) suggest that between-object competition and nontarget suppression develop over hundreds of msec. To resolve the issue we have measured the time-course of competition directly in behaviour. Following identification of one object, interference with another lasts up to half a second, then rapidly resolves (2.27). This time-course is exactly the same whether the task requires identification of one or two attributes of the first object, even though making two identification responses of course takes substantially longer. Increasing the difficulty of the first discrimination also has no effect though, as we should expect, interference is substantially increased when the first display contains two objects rather than one. The results show that high-speed serial models of visual attention are incorrect. Like nontarget suppression in the physiological data, interference in behaviour lasts for hundreds of msec.

2. Our single unit studies have dealt with both attentional templates and attentional competition in the high-level visual cortex of the monkey. Animals were trained to direct attention to different objects in a multi-object display, depending on a prior instruction cue. Recordings were made from single cortical neurons in each phase of the task. While some recordings have been made in both V4, an early input area, and the inferior convexity of the frontal lobe, the main results come from inferotemporal (IT) cortex, a visual area involved in object recognition.

In IT, we observed preactivation or priming of neurons responsive to the current target. Such priming began with the cue indicating which object was the target, and continued until presentation of the display. On arrival of the display, we observed initial responses to both target and nontarget objects, followed by rapid nontarget suppression (2.15, 2.92, 2.93).

Such results suggest the following model (2.17). In line with behaviour, there is competition between populations of extrastriate neurons responsive to different objects in a display. When a particular object is defined as behaviourally relevant, the corresponding neural population is given a competitive advantage by preactivation. The result is domination of the IT response by the target, with suppression of responses to nontargets.

Different regions of extrastriate cortex are specialised to code different attributes (shape, location, etc.) of visual objects. In our experiments, attentional selection was based on nonspatial object characteristics. The cue indicated what sort of object the target would be, not where it would appear. For the case of spatial cues, preliminary results in Desimone's laboratory suggest priming of cells with a corresponding spatial receptive field; this priming occurs earlier in the visual system than IT. The general scheme (2.24) suggested by these results is that -- for different selection cues -- local priming in different regions of extrastriate cortex can give the target object a competitive advantage. Such a scheme implies integration between visual areas: a local bias in one area leads eventually to a competitive advantage for the whole, distributed description of the selected object (2.21, 2.24).

3. Our lesion studies deal with attentional deficits consequent on parietal, occipitotemporal and frontal lesions in the human. In collaboration with Bundesen and Humphreys, a method has been developed to differentiate deficits including competitive bias against certain regions of the visual field, and poor task-dependent selectivity. One of our most general and surprising findings concerns the phenomenon of extinction. Spatial extinction consequent on right parietal lesions is well-known: objects in the left (contralesional) field can be identified when they occur alone, but are extinguished by an accompanying object on the right (see related contributions of Robertson, and Goodrich and Ward, in this report). Our results suggest this to be a special case of a much more general effect. Spatial extinction also occurs following occipitotemporal lesions, a result confirmed by Desimone in the monkey. In a case of bilateral parietal lesions, we have also observed extinction based on nonspatial characteristics; the patient identifies either a picture or a word presented alone, but extinguishes the word when both are presented together (Humphreys et al., submitted). Again, these results show integration between brain systems (2.17). A lesion which affects one object more than another, whether for spatial or other reasons, produces a competitive bias against that object. Though originally arising in one brain system, this bias is generalised to others. The result is extinction of the whole object and its associated behaviour.

The multiple forms of competitive bias produced by different brain lesions correspond to multiple strategies for rehabilitation. Robertson's work shows how neglect of visual targets in contralesional space can be relieved by irrelevant motor activity on that side. Others have obtained similar results using unilateral vestibular stimulation, or a unilateral eye patch to bias input to the colliculus (e.g. Rubens, 1985). Again, an initially local bias produces generalised results.

4. Though our PET data are preliminary, one initial result may be mentioned. When subjects make concurrent discriminations of orientation and location, we see activation of both occipital area 19 (expected from other studies of orientation discrimination) and parietal area 7 (expected for location discrimination). Other activations seem largely to be motor (cortical areas 4 and 6, caudate, cerebellum), and dividing attention between objects produces no new positive foci. A tentative conclusion is that, in this type of task, attentional competition is largely a property of the visuomotor network itself. We see no activation of "higher-order" areas such as the anterior cingulate.

We believe that these findings make a strong case for interdisciplinary research into attentional functions. Functional models define questions for physiological studies, which in turn feed back to the model level. To our knowledge, few other groups in the world have been able to assemble such an integrated cognitive, neurophysiological and clinical programme of research on high-level brain function. The findings suggest the following conclusions:

(a) Competition between objects occurs in multiple brain systems, visual and motor, cortical and subcortical etc. (2.17, 2.24).

(b) Competition however is integrated across systems. Thus a bias towards one object or region of space, initially arising in any system, is generalised to others (2.24); resulting in a tendency for multiple brain systems to deal concurrently with the same object.

(c) A particular example is integration across visual areas dealing with an object's different attributes (shape, colour, location, motion etc.) (2.95). Indeed this is needed to allow object selection based on different attentional templates. Templates for location, colour and identity are reflected in very different patterns of pre-activation or priming in the extrastriate network; yet all must finally result in selection of a whole object description.

(d) The outcome of competition in the visuomotor network is a long-lasting selective state, in which the description of a whole object gains control of response systems.

B. Selection of Goals: Frontal Functions and Intelligence *(Duncan, Emslie, Bourke)*

The integrated competition approach is well established for the case of visual attention; in this case hypotheses are relatively well worked out, and suitable lines of attack relatively clear. In this section, the approach is extended to deal with higher-order aspects of attention and control. The work has developed from a prior project dealing with general intelligence or Spearman's g, frontal lobe functions, and interference between dissimilar, concurrent tasks. We suggest that these problems are related to competition, not between perceptual objects, but between action requirements or goals. Though in comparison to visual attention these problems are less well understood, they are of broad significance both theoretically and clinically. Executive functions are emphasised in accounts of memory, planning, attention, ageing etc.; executive disorders are currently implicated in a broad range of clinical problems, including head injury, degenerative disorders, schizophrenia, depression and autism. Again, related clinical work is described by Robertson.

The concept of Spearman's g is central to the study of individual differences. Roughly speaking, g reflects a person's tendency to perform relatively well or not so well in all manner of diverse real-life and experimental activities. In the last Progress Report, we proposed that g might be largely a reflection of frontal lobe functions (2.20, 2.95, 2.96). Following frontal damage, there can be a widespread disorganisation of behaviour, manifested in activity that seems impulsive, stereotyped, irrelevant or otherwise inappropriate to task demands. In the current reporting period, we have carried out a number of studies supporting this general hypothesis. The work has been supported in part by funding from the U.S. Air Force (held jointly with Alan Baddeley), and has involved extensive collaboration with both Rehabilitation (Roger Johnson, Michaela Swales) and MRIS (Charles Freer) Units at Addenbrooke's Hospital. Major findings are as follows:

1. Conventional belief is that frontal deficits are rather unrelated to conventional intelligence. This view is based largely on the existence of patients with obvious cognitive deficits following frontal lesions, but preserved superior IQs on conventional tests such as the Wechsler Adult Intelligence Scale (WAIS). On psychometric grounds, however, changes in g after brain damage are more appropriately measured by tests of "fluid intelligence", typically involving novel problem-solving (2.96). In collaboration with Paul Burgess from University College London, we have shown massive impairments in fluid intelligence (up to 60 IQ points) in frontal patients with preserved WAIS IQs (2.73, 2.96).

2. A series of studies has dealt with a phenomenon we term goal neglect, or disregard of a task requirement even though it has been understood (2.74, 2.96). Subjectively, it is as though a task requirement "slips the subject's mind". Occasionally mentioned in the literature on frontal patients, goal neglect has also been shown to occur in normal people in our studies. Important conditions for its occurrence include novelty, weak verbal feedback on errors, and multiple concurrent task requirements. In the normal population, goal neglect is very closely related to g, though the task is simple and has no apparent element of problem-solving. Under the same conditions, goal neglect is extremely common in frontal patients.

At any given time, behaviour is shaped by a set of requirements or constraints, specified at multiple levels of abstraction (2.74, 2.96). An example is a conventional goal-subgoal hierarchy. We suggest that goal neglect provides a simple behavioural model of a general frontal process of shaping behaviour by activation and competition of appropriate action constraints; and that variability in this process is largely reflected in Spearman's g.

3. In a third project, we attempted both to segregate frontal impairments into distinct components, and to separate them from impairments less sensitive to frontal lesions. A large battery of conventionally "frontal" tests (e.g. Wisconsin card-sorting, verbal fluency) and conventionally "nonfrontal" tests (e.g. recognition memory, object recognition from unusual views) was administered to a series of 90 head injured patients. Head injury was chosen because of its highly variable damage, often with a strong frontal element. From each test we obtained both overall scores, and scores related to putative frontal subfunctions such as switching cognitive set or inhibiting inappropriate behaviour.

Four results are noteworthy. First, correlations between different measures were generally low, in the range of 0.3. In particular, the conventionally "frontal" tests did not correlate more strongly with one another than with the "nonfrontal" tests. Second, extracting more detailed measures from each test -- e.g., measures of inhibition from two different tests -- produced even lower correlations. Third, average performance in a range of 6 "frontal" tests was correlated around 0.6 with fluid intelligence. Both were weakly related to frontal damage as assessed on MRI; the relationship was strengthened if an estimate of premorbid IQ was partialled out. Fourth, the same average was even more closely related to our standard measure of goal neglect, showing that even patients with apparently different profiles of "frontal" deficits share a common impairment. Our hypothesis is that each separate test simply provides a weak opportunity for the common deficit to be revealed.

These findings notwithstanding, it is obvious from animal work that frontal cortex is in some respects heterogeneous, both anatomically and functionally. A clear question for the future is how an integrated behavioural function such as goal selection or activation can arise from the activity of separate frontal subfunctions.

4. Our final studies concern a possible "general factor" in dual task interference, and its relationship to the g factor of psychometrics. It is well known that concurrent tasks are especially prone to interference when they are obviously similar, for example when they share input or output modality. The competition between one visual object and another described in the previous section is one clear example. Some interference remains, however, even when tasks are as dissimilar as possible.

In one series of studies (2.71, 2.72, 2.157), Bourke asked whether a single, general source of dual task interference accounted well for the data when superficial task similarities were avoided. In this case, tasks should be ordered in demand on the general factor, and the order obtained should be consistent no matter what concurrent task was used to measure it. Results confirmed this prediction, suggesting the possibility of a principled scale for measuring the general "demand" of different tasks (2.71).

One hypothesis is that interference between dissimilar, concurrent tasks might reflect conflict within those same action control functions that we have related to g. In this case, a concurrent task might act like a simple reduction in g; across any set of tasks, profiles of g correlation and dual task decrement should be similar. In an initial study, this prediction was confirmed for impairments in 12 driving skills, produced by concurrent generation of random letters (2.29). Baddeley's development of the random generation task is described elsewhere in the Report; for present purposes random generation provides a convenient way to avoid stereotypy in a task with minimal input and simple output. The prediction was confirmed in a second study using 15 conventional psychometric tests; when the concurrent task was changed from random generation to tone discrimination, however, results were rather less clear. A more fine-grained analysis of dual task conflicts will be needed to relate them clearly to g.

C. Inhibitory Control *(Houghton)*

A variety of phenomena in visual attention (negative priming, inhibition of return, interference) have been taken to reflect direct inhibition of irrelevant inputs. In negative priming (Tipper, 1985), for example, responses to a current target stimulus are slowed down if this stimulus has previously been ignored. In a collaboration with Tipper (2.113), Houghton produced a detailed simulation of negative priming and other phenomena based on inhibition of ignored representations. The sources of inhibition were related to specific brain systems; on this basis, the model has since been extended to data from impaired populations including Parkinson's disease and neglect patients, and to other forms of cognitive inhibition.

FUTURE PROPOSALS

Our general interdisciplinary approach is already proving itself for the case of visual attention. In our proposals this approach is continued and strengthened. At the same time, we have made moves to establish a similar, broad approach to the problem of frontal lobe functions.

The collaborations we have already established outside the APU are continuing, and new ones developing. For functional activation studies of frontal lobe functions, we have established a collaboration with the PET group at Heinrich-Heine University in Dusseldorf (Rudiger Seitz). As functional MRI (fMRI) develops over the next 5 years, we should also expect to gain the increased temporal resolution it allows. Later we shall describe the steps already taken in this direction.

In fact, the opportunity exists to establish the general research programme much more centrally in Cambridge itself. This would involve collaboration between a number of Cambridge laboratories, with a central role for the APU. Later we shall describe the basis for such an development, the support it would need and the progress made so far towards it.

A. Visual Attention *(Duncan)*

We have suggested that the phenomena of visual attention reflect competition between objects in a distributed network of visual and motor systems. We propose studies to amplify this model at the levels of both behaviour and brain systems, and in collaboration with Robertson (see his section of this report, in Neuropsychological Rehabilitation), to develop useful clinical techniques for the treatment of attentional disorders.

A1. Scope of Interference: What is the basis for the extended interference we have observed between visual targets presented at temporal separations up to 500 msec? One hypothesis is that interference reflects mainly competition within visual processing structures, but supramodal and other, broader aspects of attentional competition have also often been proposed. More generally, it has often been suggested that interference between concurrent activities reflects brain systems they require in common (e.g. Allport, 1980). This hypothesis will be tested using converging behavioural and functional activation studies.

In fact, we have pilot data already to suggest that interference is all but eliminated when one target is visual and the other auditory. If confirmed, such results will lend strong support to the hypothesis of specifically visual competition. In a parallel functional activation study, pairs of visual and auditory stimuli would be presented. In different conditions, subjects would identify both stimuli in one modality, or stimuli in different modalities. We predict competition (e.g. reduced activation for both right and left visual stimuli) in the within-modality case, but parallel activation of modality-specific systems. Following our previous PET results, we predict little activation of supramodal systems for these simple, well-practised discriminations.

A second interesting case would be concurrent, lateralised motor activity. Robertson's work on rehabilitation of visual neglect has suggested integration between spatial biases in visual and motor systems. To examine such integration, we should present a visual object to left or right, accompanied by a distractor in the contralateral field. At varying intervals surrounding this display, a central auditory stimulus would call for a lateralised manual response. Integration would be indicated by a visual bias initiated by the manual requirement.

Following on from this study, we should examine visual biases consequent on other aspects of movement. The parietal lobe of the macaque, for example, contains neurons active both during a particular kind of action (e.g.

pulling) in the dark, and in response to a visual input suitable for such an action. In general, does performance of some action bias the visual system towards inputs "affording" that action?

Finally we shall ask what factors influence the duration of interference between one visual object and another. When does one object's demand on the visual system resolve? Our findings to date suggest that the duration of response selection operations is immaterial, but this needs to be confirmed. An interesting hypothesis is that each eye movement clears the previous selective state, setting the stage for the next.

A2. The Attentional Template: We have suggested that, at least in part, the attentional template is implemented by priming of extrastriate neural populations. Issues arising include the distinct representation of templates coding different object properties such as location or shape; the coordination implied by using a local template to guide selection of a whole object description; and interaction between extrastriate and frontal systems.

A continuing collaboration with Desimone at NIMH addresses coordination between visual areas. When monkeys search for a target object, we find template-like activity only late in the visual system. Neurons selective for the target are pre-primed in inferotemporal (IT) cortex, but not earlier in IT's main input area V4. What of the subsequent suppression of nontarget responses seen in IT when the visual array is presented? Our preliminary data suggest that, in the earlier area V4, such suppression develops later in the visual response, as if fed back from the higher-order system. Such a pattern of interaction between areas is exactly what we would need to coordinate whole-object selection and suppression. To support such a picture, the data need confirmation and extension to other selection tasks with other kinds of template activity.

For the human, a broader set of hypotheses may be tested. Specialisation of an occipitoparietal system for spatial vision and an occipitotemporal system for object vision is well known. We propose that priming of parietal neurons will be involved in location-based templates, and thus in controlling selection by a spatial cue, while occipitotemporal priming is involved in object-based templates, and thus in controlling selection by object features. Close connections are also known, however, between parietal and dorsal prefrontal cortex, and between inferotemporal and more ventral prefrontal cortex; and there are good reasons from others' work to suppose that these prefrontal regions are involved in holding cues to guide future behaviour (e.g. Funahashi, Bruce & Goldman-Rakic, 1989). In general, frontal systems seem especially important when behaviour must be altered; in the present case, we expect greater prefrontal involvement when target locations or objects must switch from trial to trial. Related and broader experiments dealing with frontal functions and practice are presented in a later section.

Ideally, these hypotheses will be tested in both lesion and functional activation studies. For the lesion studies, we shall compare selection deficits following parietal, occipitotemporal and frontal lesions. Encouraging pilot data for the first two groups have already been obtained. We shall compare spatial and nonspatial selection cues, either fixed or varying between trials. With fMRI, it may be possible to image activity in the period between presentation of a cue and the subsequent visual array. In this way we should specifically target the kind of sustained priming activity we suggest is important in the attentional template. We predict parietal activation for spatial cues, and occipitotemporal activation for object cues. A particularly interesting result would be differentiation of more dorsal and more ventral frontal activations during spatial and object tasks with varying cues.

A further important case is long practice with search for a particular target. In this case, the familiar target seems automatically to draw attention to itself. A possible study in both human and monkey is to investigate changes in template-related activity when practice is prolonged.

A3. Extinction and Integration: Contralateral neglect and extinction are common in the acute phase following a unilateral cerebral insult. With time the most severe problems may resolve, leaving subtle disorders manifest on detailed examination. According to our hypothesis, a competitive imbalance in one brain system can be transferred to others, producing widespread consequences of even a restricted lesion.

Using the brief exposure techniques we have already developed to measure subtle forms of visual extinction, we shall pursue our observation that this disorder is common to many forms of unilateral lesion. Of particular interest will be the visual consequences of lesions to various parts of the motor system, including posterior frontal cortex and the basal ganglia. At the same time we shall develop our work on nonspatial extinction. Our hypothesis is that, whenever a brain lesion affects the representation of one object more than another, a consequence is competitive bias against the impaired object when both are presented together. For example, it has been reported (Robertson & Lamb, 1991) that left and right temporoparietal regions are specialised for respectively more local and more global objects; we shall explore the consequences for extinction when both kinds of object occur together.

In parallel with these studies are those described by Robertson in the Neuropsychological Rehabilitation section of this report, dealing with clinical implications and tests of the general competitive model.

B. Selection of Goals: Frontal Functions and Intelligence *(Duncan, Bright)*

In this section we describe behavioural, lesion and functional activation studies of dual task interference, frontal functions and g. Linked clinical studies are described by Robertson (see his section of this report, in Neuropsychological Rehabilitation).

B1. Dual Task Interference: As we have said, there is generally interference when two tasks are performed at once, even when those tasks are maximally dissimilar. According to Bourke's work, such interference suggests competition for a single, common system or resource, and we have suggested it may be closely related to g. In fact, little is known about this rather general form of dual task interference. We plan to investigate it in detail. Following the strategy we have used for visual interference, we shall begin with a study of time-course. The literature suggests two factors that might contribute to interference between very dissimilar activities. First, there is the "psychological refractory period", reflected in interference when two responses must be selected or two facts retrieved simultaneously. This form of interference takes the form of a real-time processing bottleneck. Second, there is a much longer-lasting difficulty in keeping the rules or control structures of two tasks active at once. This difficulty is reflected in interference even when stimuli for two tasks are separated by hundreds of msec, and subjects can prepare for one or the other. By presenting stimuli at varying temporal separations, we shall ask which form of interference acts like Bourke's "general factor", and which is related to g correlations.

In the context of vision, we have already proposed one test of the general hypothesis that dual task interference reflects demands on common brain systems. As a converging test of the same hypothesis, we should like to conduct a functional activation study of dual tasks and practice. Practice is a major factor reducing dual task interference; subjectively, practised behaviour becomes "automatic". Among the effects of practice, the PET literature suggests reduction in frontal activation. To investigate this link, we should measure local cerebral activity in both single and dual tasks, early and late in practice; mapping changes in cerebral activation to changes in dual task conflict.

B2. Frontal Functions and g: In our collaboration with the Dusseldorf PET group, we have begun work on a functional activation study designed to test the hypothesis of a close link between frontal lobe functions and g. It is well known that fluid intelligence tests can be based on very different materials, e.g. verbal and spatial. These tests have similar, high g correlations; our question is what they share in terms of cerebral activation. For use in PET, we have developed three tests with high g correlations, one verbal, one spatial, and one perceptual-motor. Each is paired with a control, based on similar materials and operations but with a lower g component. The three control tests will of course show very different patterns of regional cerebral activation. Our question is how each pattern is modified in the high-g case. Three broad hypotheses may be distinguished. First, different high-g tests may activate common frontal regions. For example, broad activations of both dorsolateral prefrontal and anterior cingulate regions have previously been described for a range of relatively complex tasks.

Second, high-g tests may activate largely content-specific cortical areas. Based on known content-specificity of monkey frontal cortex, this may be the picture for both frontal and posterior regions. Third, increasing a test's g correlation may simply increase involvement of a broad range of cortical systems; in line with the idea that g reflects some overall average of many different functions or skills. In general, our question is how a unified construct such as g relates to modular cerebral organisation.

In a linked study, we shall compare the deficits of patient groups with lesions in different major subdivisions of the frontal lobe (see below). The literature shows frontal deficits in an enormous variety of different tests, with little in the way of principles predicting which tests will be most sensitive. We predict that a major factor should be a test's g correlation: the higher the correlation, the greater should be the frontal deficit. This prediction will be tested both for specific frontal groups, and as a baseline against which to assess more specific impairments.

B3. Goal Neglect: Based on our work to date, we have suggested that goal neglect may provide a simple behavioural model of action control functions that are basic to both frontal impairment and Spearman's g. In general, these functions concern the shaping of behaviour by activation of appropriate task constraints or requirements. To address these functions in more detail, our analyses of goal neglect will be extended and developed.

A first step is generalisation. Our hypothesis is that, whenever a task is novel and has multiple concurrent requirements, one requirement can lose activation and hence control over behaviour. To date, however, the work has been based on one specific test, involving switches of attention between one high-speed stream of visual input and another. An additional problem is sensitivity: In the current test, goal neglect is restricted to around a quarter of the normal population. To address these problems, we are developing a second test which is quite unlike the first. There is no speeded input, and no call for a switch of attention; we simply give subjects a central task (finding groups of words with related meanings), and add additional, independent requirements. With this test we plan parametric studies of the number of concurrent requirements, the order in which they are presented, and individual differences in g. Pilot data confirm that goal neglect is commonly observed, at least in elderly subjects.

When this test has been developed, a number of extensions will be undertaken. First, the head injury project we have described suggested that goal neglect is a difficulty common to patients with very different profiles of "frontal" impairment. A possible hypothesis is that a general goal activation function - central to Spearman's g - arises from integrated activity in separate frontal systems. To test this hypothesis we shall assess neglect following lesions of distinct frontal regions, and compare with posterior lesion controls. Second, neglect is sensitive to task complexity or number of requirements, but we should also like to investigate other aspects of difficulty, less directly related to requirement activation and frontal function. To link to our visual studies, we shall investigate simple discriminability - which has no effect on an object's demands on visual attention - and whether requirements to be concurrently activated concern the same or different objects. Third, the phenomenon of goal neglect has much in common with the problem of "prospective memory" (see contributions by Maylor and Sellen in the Memory section of this report), or remembering to satisfy an intention. To investigate this link, we shall study the effects of delays and interfering activity between initial goal specification and subsequent requirement to perform.

C. Inhibitory Control

With Houghton's departure this topic is continued elsewhere.

Centralising the Programme in Cambridge

Though the interdisciplinary programme we have described has been based largely on outside collaborations, this approach has obvious disadvantages. Collaborators in other laboratories have their own priorities, day-to-day involvement in the research is lost, and the work depends on continued success in attracting outside funding. In fact, the opportunity exists to centralise much of the existing programme in Cambridge, based around a number of new developments in other institutions. This is a possibility which, in consultation with the Visiting Committee and new Director, Duncan is keen to explore. We briefly outline the opportunities that exist and some potential costs.

Funding already secured for establishment of a Functional Brain Imaging Centre, based at Addenbrooke's Hospital under the direction of Professor John Pickard (Neurosurgery), will make both PET and fMRI available in Cambridge within the next few years. An additional request for core funding to support clinical research into closed head injury is under consideration by the MRC; Duncan, Robertson and Baddeley have all been closely involved in this development. Meanwhile, Duncan has also been establishing pilot collaborations with Professor Laurie Hall (Medicinal Chemistry), who will take primary responsibility for establishing fMRI in the new Centre, and in the interim is conducting pilot studies in his own department. The expertise we have already developed through outside collaborations will be of undoubted benefit to the Centre's work, and places us well for studies of normal volunteers and clinical groups other than head injury to complement the Centre's own programme.

To support such studies, however, and to give the APU a viable role in the Centre's work, would probably require commitment of at least two scientific posts.

Investigating the functional consequences of human brain lesions has of course been a major part of the APU's programme for a substantial period. When lesions are well characterised, the technique is complementary to functional activation. To optimise such studies, as well as functional activation studies of patients themselves, structural brain lesions must be characterised with the same precision as, and in comparable coordinates to, functional activations. In collaboration with John Pickard (Neurosurgery), Charles Freer (MRIS Unit), Laurie Hall (Medicinal Chemistry) and Trevor Robbins (Experimental Psychology), Duncan has begun to establish a panel of stable patient volunteers for neuropsychological research, with CT- or MRI-imaged lesions mapped to standard coordinates. We are establishing a number of focal lesion groups, including groups with lesions in distinct subdivisions of the frontal lobe as well as posterior groups. Again, this endeavour is of broad benefit to APU research. A full-time scientific officer would be able to support both this development and Duncan's work with normal subjects.

More remotely, the potential of animal work in Cambridge should also be considered. At the new Innes Centre, the MRC is currently establishing a major programme of neuropsychological work with the marmoset. This programme is under the direction of Rosalind Ridley. Though a major collaboration with animal research would be a novel departure for the APU, our work with Desimone's group shows the potential of this approach. With its combination of fine temporal and single-neuron spatial resolution, primate electrophysiology offers a detailed, direct view of brain activity. An attractive approach is to follow gross spatial studies of human brain activation with detailed investigation in the primate. Preliminary discussions with Dr. Ridley suggest a clear possibility of collaborative work on frontal lobe functions.

There are obvious attractions to linking together these different developments in Cambridge, many already supported by the MRC. At the same time, the momentum for such an enterprise needs to come from a specific, integrated research programme of the sort Duncan has developed. We should expect broad benefits not only for the APU's programme as a whole, but for the MRC's other investments in Cambridge as well. We are keen to discuss the desirability of such an approach, and how it might best be integrated into the APU's programme.

SELECTIVE ATTENTION

(Lavie)

Introduction

Three primary questions have been the focus of selective attention research.

1. What causes selection to occur?

A major issue is the extent to which attentional instructions can result in selective perception of task-relevant stimuli. The work detailed in section A attempted to resolve this issue by proposing a model for selective attention that specifies the conditions under which attention would result in selective perception.

2. When selection does occur, what is it based on?

Both response selection and perceptual selection require some degree of physical distinction between the stimuli that are selected for further processing or response, and those that are not selected. Section B describes work investigating the nature of the various stimulus dimensions available to control selection (e.g. colour, shape, location). The studies detailed in B have specifically focused on describing the nature of space-based selection and its contrast with object-based selection.

3. Which perceptual processes do not require selection, and operate independently of attention?

The work detailed in section C has centred on designing a new test for the prevailing attentional theory of Feature Integration (e.g. Treisman, 1988), which claims that the perception of separate features (e.g. colour, orientation) is preattentive, i.e., can proceed without requiring focused attention. On this theory, focused attention is only needed when perception of the particular conjunctions of features into objects is required.

Since Lavie arrived at the APU in October 1994, her report of past studies mainly describes research on programs that began before arrival at the APU. More emphasis has been given to future plans.

A. The Role of Information Load in Selective Processing

A1. Studies of Visual Attention: One of the basic questions in the study of selective attention is whether the perception of irrelevant information can be avoided. This issue led to the long-standing debate on early versus late selection. The early selection approach claims that selective attention results in selective perception. By contrast, the late-selection approach claims that perception proceeds automatically, regardless of selective attention. A definitive resolution of this issue has proved elusive over three decades of research, which have produced some support for both sides of the argument. Lavie has proposed a new approach to this debate which seems capable of resolving previous discrepancies (2.41; Lavie, 1992). She suggested that a major determinant of whether selective perception takes place is the information load imposed by processing task-relevant information. Identification may proceed automatically until perceptual capacity is exhausted. On this view, whether or not irrelevant stimuli are identified should depend on the capacity demands imposed by relevant processing.

A review paper which re-examines previous findings from this perspective provides clear support for the load hypothesis. Results of early selection have usually been obtained in high load tasks; late selection results have been obtained when the relevant processing carried a low load (2.41). This review has also considered the role of physical distinction between relevant and irrelevant stimuli in the task in determining the efficiency of selective processing. This factor was previously held to be the major determinant of selection; but the review points out that, on its own, physical distinction between relevant and irrelevant stimuli leads to apparent discrepancies in results, whereas a combination of physical distinction plus relevant information load provides a resolution. The conclusion is that physical distinction between relevant and irrelevant stimuli is a necessary condition for correct selective processing, but it is not a sufficient condition for the occurrence of selectivity, as long as task-load is low.

Lavie has continued with empirical studies, testing this hypothesis directly. New experiments varying the load of the relevant processing have shown that this variable determined the level of processing for distracting information (2.42). This result was obtained with a number of converging operational definitions of load in relevant processing. These included varying the number of items relevant for processing, and varying the processing requirements for identical displays (e.g., simple detection versus difficult discrimination or feature versus conjunction tasks).

A2. The Load Hypothesis and Studies of Neuropsychological Impairment: Since the studies on normal subjects show that increasing the load of relevant processing can help in the rejection of irrelevant information, implications are raised for patients with lateralized damage (typically stroke) to the parietal lobe. These patients suffer from 'neglect' of visual information presented to their contralesional side, especially when ipsilesional information captures their attention (see sections by Duncan, Goodrich and Robertson in this report). On the load theory for selection, increasing the demand of relevant processing (e.g., by requiring patients to process two relevant letters rather than one) should help eliminate the distraction from irrelevant information in the ipsilesional field. A study that tests this hypothesis is currently being conducted (in collaboration with Ian Robertson), with initial results supporting the prediction.

B. Objects and Space

Lavie's model for selective attention (detailed in section A) attempted to clarify the interactive role of load and physical distinctiveness in determining selective attention. There are however important questions regarding the definition of physical distinctiveness. In her past work with Tsal (Tsal & Lavie, 1988; Tsal & Lavie, 1993), Lavie has argued that not all dimensions of stimuli are equally efficient for selection (c.f. Duncan, 1981). They suggested that space-based selection underlies selection by other attributes such as colour or shape.

A major controversy in recent studies concerns the role of empty space per se, versus the perceptual objects that occupy the space, in determining attentional selection (e.g., Duncan, 1984). Location-based selection studies have usually shown the importance of space effects when distance is manipulated between separate objects (e.g., Tsal & Lavie, 1988). By contrast the theory of object-based selection has been supported in studies which manipulated the separation or integration of attributes into objects, while holding distance between the attributes constant and usually near (e.g., Duncan, 1984).

It remains unknown what selection will be based on when the two selection-rules are set against one another. In other words, would object-based selection break down when the attributes to be selected are grouped into one object but over a wide spatial area? Conversely, should distance between the attributes matter once an object is selected? A study in which both spatial separation and object integrality are manipulated orthogonally within the same widely-spaced situation is required to answer these questions. Lavie (in collaboration with J Driver at the University of Cambridge) has designed such a situation in a recent study, comparing performance in judging two attributes which are close or distant either within the same large object or in two separate objects. Preliminary results show that object effects can be obtained even when the object links attributes over a very large space, provided that spatial attention is diffuse. On the other hand, when attention is spatially focused on a narrow region (following a precue), object segmentation over larger spaces no longer has an effect.

C. FIT and Response Competition Effects from Unattended Distractors

In contrast to the view of perception as a unitary process, the prevailing Feature Integration Theory (FIT) of attention (e.g., Treisman, 1988) proposes a major distinction between perception of separate features and of conjunctions of those features to form multidimensional objects. According to FIT, unattended visual features are registered on separate feature maps (e.g., colour maps, orientation maps, etc.). One role of focused attention is to conjoin the separate features into consciously seen objects. Thus, for unattended objects, only the separate features are known (e.g. blue, green, circle, triangle), but not their specific combinations (e.g. a green triangle, and a blue circle). Although this theory has been tested extensively in the paradigms of visual search and of illusory conjunctions, those lines of evidence remain equivocal (see for example: Duncan & Humphreys, 1989; Tsal, Meiran & Lavie, 1993).

Lavie has designed a new test for FIT, using the response competition paradigm. The response competition paradigm provides an indirect procedure for assessing the perception of unattended items, by measuring their effects on the response times to attended items. The unattended items may either be compatible or incompatible with the relevant response. Perceiving the identity of the unattended distractors should lead to longer RTs for targets that appear with incompatible rather than compatible distractors.

According to FIT, the compatibility effects of irrelevant distractors which include target features should not differ according to whether the target features are conjoined within one distractor object or disjoint between two distractors. If distractors are unattended, their features remain unconjoined. In Lavie's study subjects were requested to respond to targets which were defined by conjunctions of colours and shapes (e.g., respond to a purple cross or a green circle, and withhold response to a purple circle or to a green cross). They were also requested to ignore irrelevant distractors that flanked the target on both sides. The features of the distractors could either be compatible or incompatible with the target, but more importantly, the same incompatible (or compatible) distractor features were either conjoined in one of the distractor items (e.g. a green circle) while the other distractor had neutral features (e.g., a blue triangle); or the distractor features were disjoint across two of the distractor items (e.g. a blue circle and a green triangle). Hence, the same distractor features appeared in both types of trials (conjunctive or disjunctive). Only their combinations into objects varied.

The results of this study supported the Feature Integration theory. Both conjunctive and disjunctive distractors had significant compatibility effects of equivalent magnitude, suggesting that the unattended features were not conjoined into individual objects.

FUTURE PROPOSALS

A. The Role of Information Load in Selective Processing

A1. Load and the Efficiency of Visual Search: The load hypothesis has interesting implications for previous accounts of the efficiency of visual search. On the load account, as the relevant search task becomes easier, prevention of irrelevant processing becomes harder. A study in progress has manipulated determinants of efficient search, such as the degree of similarity between target and non-target items in the search task (as discussed by Duncan & Humphreys, 1989), and measured their effect on the prevention of irrelevant distraction. Preliminary results support the contention that more efficient search among the relevant items results in a less efficient rejection of the distractor.

A2. Implications of the load hypothesis for neuropsychological patients and elderly subjects: In addition to studying effects of relevant load on the distraction potency of ipsilesional items in neglect patients, there may be more general implications of the load hypothesis with regard to patients and elderly subjects who have abnormally restrictive capacity limitations (see Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991). These populations should perform better than normal on selective attention tasks, in the following restricted sense. They should be less susceptible to interference from distractors under low load conditions, since less spare capacity should be available for processing these distractors. Studies on this issue will be conducted in collaboration with Ian Robertson and Elizabeth Maylor.

A3. What is the Nature of Load that is Relevant for Selective Processing? Thus far Lavie's studies have shown that loading a task makes rejection of irrelevant information more efficient. Should we conclude that difficult tasks in general lead to more selectivity? This issue will be studied in several ways:

A3.1 The role of data- versus resource-limitations in the processing of irrelevant information: The concept of perceptual load encompasses more than just delayed RT or increased difficulty. It implies that the system must carry out further operations, or must apply operations to additional units. It is these additional demands on capacity, rather than a mere delay in processing, which should block low-priority, irrelevant items from consuming spare capacity. By contrast, data limitations on perception, while increasing task difficulty, should not impose additional demands on capacity, as increases in resource allocation cannot compensate for data degradation (Norman & Bobrow, 1975). Thus, the process of perception for degraded relevant information should be merely prolonged. Indeed the chance of distractor intrusion during this extra time may be even be increased (e.g., Eriksen & Schultz, 1979; Navon, 1988).

Thus, according to the load hypothesis, data limitations in relevant information should actually have the opposite effect on irrelevant information processing to increases in relevant load (i.e., resource limitations), even though both factors make any task harder. Studies that test this account are currently being conducted, in which load is manipulated by the number of relevant items. Data limits are induced by either reduced acuity for more peripheral targets, smaller and lower contrast targets, or masking characters superimposed on the target position.

A3.2 Types of load: Does loading post-perceptual routines (e.g., response selection, memory) result in a similar effect to the perceptual load manipulations discussed above? There are grounds to expect that loading a more central aspect of control, responsible for setting up and maintaining the priorities in a task, should lead to confusion, i.e., a reduced distinction between high- and low-priority items, resulting in impairment of selectivity. It should be interesting therefore to contrast the effect of loading early perceptual processes versus late response-selection processes within comparable tasks.

A3.3 Auditory load and selective attention: There is evidence for general limitations in capacity which hold across modality (see Duncan's section in this programme). Thus, one might extend the load hypothesis across modality to predict that selectivity in vision would improve under increased load in the auditory modality. In a preliminary study conducted in collaboration with Richard Ivry (UC Berkeley), we are investigating whether load in semantic processing for auditory stimuli can eliminate Stroop-interference from an irrelevant visual word on responses to colour patches.

A4. The Relationship Between Load and Other Factors Influencing Irrelevant Processing

A4.1 The relationship between perceptual load and spatial cueing: In a study by Johnston and Yantis (1990), cueing the location of a target in advance resulted in successful rejection of information in irrelevant locations. The displays used in their study were characterised by high perceptual load, and thus it is difficult to determine the roles played by either cueing or load. In a collaborative study with James Johnston (of NASA-Ames, California), both cueing and load are manipulated in a factorial design in order to study their contributions in determining selective processing. Initial results suggest that load and spatial cueing interact such that effectiveness of cueing is greater with high loads.

A4.2 Attention capture: The load hypothesis suggests that spare capacity inevitably 'spills over' to distracting information once the relevant processing required by the explicit task has been completed. However, it may be possible to prevent this without any increase in load. It is known that some factors (e.g. abrupt onsets) are particularly effective in attracting attention. This raises the possibility that interference from distractors may be prevented, even under conditions of low load, provided the relevant stimuli are sufficiently attention capturing (e.g., they flicker) to continue to attract any spare capacity.

A5. Testing the Extent of Voluntary Control in Selective Attention Tasks: One of the implications of Lavie's previous load studies is that selective perception is involuntary in the sense that it is more intimately related to the load of the relevant task than to the subject's intentions to be selective. When the load in the relevant task is low, subjects apparently cannot ignore the distractors, even though this is explicitly required and failure to comply with the requirement impairs performance. The extent to which attending to/ignoring distraction is involuntary seems to have significant applied consequences. In education, for example, there is little point in emphasising instructions to ignore distraction if this is not under voluntary control. It therefore seems important to investigate whether distractor processing is truly involuntary by directly manipulating subjects' motivation and expectations in the task. (for example, increasing motivation by offering some reward for selective processing, or changing expectations by manipulating the relative frequency of different kinds of distractor).

B. Objects and Space

The popular "spotlight" metaphor for visual attention implies that attention is primarily a spatial phenomenon. Tsal and Lavie (1988, 1993), suggested a more specific role for location in controlling visual selection. Although subjects can use various dimensions as cues for selection (e.g. colour, shape), Tsal and Lavie proposed that this proceeds by means of allocating attention to the location of the colour or shape cue. In several studies they demonstrated that when a target was selected by colour (i.e., subjects were requested to report a red item) or by shape (i.e., report an angular letter), neighbouring stimuli with a different colour or shape were enhanced, whereas nonadjacent items with the target colour or shape were not. In addition, a 'spatial carry-over' effect was established: subjects were subsequently faster if the next target appeared at the same location, even though location was completely irrelevant to the explicit task. There was no analogous colour or shape carry-over if the target was specified by location and colours or shapes were repeated from trial to trial.

A number of theorists have recently claimed that "perceptual groups", rather than positions per se, are the targets of visual attention. It is suggested here that these studies can be reconciled with the special role for location proposed above, if we assume that perceptual groups are selected by means of their location, analogously to the coloured stimuli discussed above. This proposal will be tested in several ways, for example by looking for spatial carry over effects analogous to those observed by Tsal and Lavie (1993) in the situations which have previously produced evidence for perceptual grouping effects.

C. FIT and Response Competition Effects from Unattended Distractors

Further investigation of compatibility effects for conjunctive versus disjunctive distractors is planned along several lines. One direction will be to measure whether factors that are known to affect feature integration in visual search paradigms have a similar effect on the extent to which response competition is based on separate feature processing. For example, will the distance between the two distractors affect the extent to which disjunctive distractors produce interference? Another direction would investigate the relationships between processes of feature integration for distractors and the load of relevant target processing. Given that the task used in Lavie's previous FIT study seemed to carry an intermediate level of load, a few questions arise. (i) Would increasing load in the central target task eliminate the distractor effects, given that they may be produced by an early stage of separate feature registration? (ii) Would reducing the load in the present task provide an advantage for the conjunctive distractors over the disjunctive ones, by allowing sufficient spare capacity to produce (involuntary) feature conjunction for the distractors?

ATTENTIONAL IMPAIRMENTS *(Goodrich, Ward)*

Introduction

At any moment in time, we are aware of, or can attend to, only a limited number of visual events from the hundreds potentially available to us. Theories of normal attentional function commonly consider objects in the visual world to be competing for limited attentional resources. It is the winners that are selected and reach awareness; the losers might be disregarded or simply fail to reach awareness. The following studies explore factors which can influence this competition for attention.

The subjects were patients with attentional dysfunction following neurological impairment. Disabling deficits in selective attention are relatively common following unilateral brain damage, especially to the parietal lobe. Patients ignore information on the side of space contralateral to their lesion, even though it can be demonstrated that this information is processed perceptually, leading to the belief that the neglected information suffers from a 'lack of attention' rather than a lack of perceptual processing (other work on neglect is discussed in the sections of this report by Duncan, Marcel and Robertson). A second group comprised people with Parkinson's disease. Within this category exists a subgroup with 'frontal' signs who appear to have difficulty on performance of tasks with specific attentional requirements.

The goal of these studies is to understand attentional dysfunction subsequent to brain damage in terms of damage to the normal components of selective attention, and so contribute to the development of theories of normal attentional mechanisms. In addition, such theories contribute to the development of rehabilitation interventions.

A. Visual Attention and Extinction *(Goodrich, Ward)*

We began a new series of studies aimed at relating the phenomenon of visual extinction, frequently found following unilateral parietal damage, to models of normal visual attention. We applied the notion of competition between target items for limited capacity processing to the phenomenon of visual extinction (2.61). By this account, the effect of unilateral parietal damage is to weaken the competitive strength of contralesional items. When two items are simultaneously presented, the more ipsilesional item wins the competition for selection at the expense of the contralesional item. However, when the contralesional item appears alone, it can still draw attention to itself, since there are no other competitors within the display. Extinction may therefore simply be a spatially specific exaggeration of a normal attentional limitation, arising from competition between multiple targets.

A1. Perceptual Grouping and Selective Attention: Within this framework, we have employed visual extinction as a technique for investigating factors underlying the competition for attention. Using subjects with unilateral parietal lesions, we find that under conditions of brief exposures, detection of contralesional items is improved when contra- and ipsilesional items form a good perceptual group (2.61). We argue that compe¬tition for selection is sensitive to the representations given to possible targets: when targets are represented as elements of separate groups, they compete for limited attentional resources; when they are represented as elements within a group, they become allies, rather than competitors, for selection.

We have utilised the extinction paradigm to explore the competition for selection between different types of visual representation. For instance, do object representations compete as integrated wholes, or as lower-level attribute values? We now have initial evidence comparing the rate of extinction for line drawings of objects versus scrambled versions of these same line drawings. The results suggest an object superiority effect in extinction: whole drawings show signifi¬cantly less extinction than scrambled drawings -- that is, whole drawings are stronger competi¬tors for selection than scrambled collections of the same features.

In a further extinction study, we looked at competition between items in terms of their spatial organisation. Our results show that extinction is greater when right and left items are horizontally, rather than diagonally, aligned about a central fixation point. Further work is required to determine whether this advantage for diagonal items reflects a dissociation between items represented in upper versus lower visual fields, or whether competition for selection is increased when items are spatially mirrored in right and left space.

A2. Non-perceptual Task Variables and Selective Attention: In a second series of studies, we explored the relationship between visual competition and non-perceptual task variables. We report a patient who, following right parietal damage, showed the opposite of the normal extinction pattern ('anti-extinction'). On brief visual presentations, he consistently showed improved detection and identification of contralesional items when presented with an accompanying ipsilesional target.

Interestingly, this benefit for contralesional items on simultaneous presentation only holds when the same task is performed with both contra- and ipsilesional items. In other words, a common task specification for contra- and ipsilesional items appears to reduce the severity of his attentional deficit. This beneficial effect of common task variables between target items provides a clear demonstration that attentional deficits resulting from parietal damage can be mitigated by non-perceptual task variables.

B. Identifying Factors which Reduce Unilateral Neglect *(Goodrich)*

B1. Intermodality Interactions: Unilateral neglect can be found in each sensory modality, and in some cases may be restricted to a single modality. Work with normal subjects has shown strong links between attentional mechanisms across modalities (Driver & Spence, 1994). If subjects attend to a specific location in one modality, it is difficult for them to attend elsewhere in a different modality. We (with Jon Driver, University of

Cambridge) explored whether these intermodality links could be exploited in order to alleviate neglect (i.e., as a way of biasing selection).

We began with the effect of touch on visual neglect in a line bisection task. Subjects had to bisect a wooden rod with their ipsilesional index finger after feeling the full extent of the rod with the same finger, which was moved either actively or passively. Active tactile information reduced neglect (the degree of rightward displacement was reduced) compared to the passive condition. The advantage we have found for active over passive touch is consistent with 'premotor' theories of attention which suggests that attending to a location in space requires programming a movement towards it (Rizzolatti & Gallese, 1988).

B2. Ipsilesional Capture in Unilateral Neglect: We (with Driver) have also begun a series of studies investigating the notion of ipsilateral capture in unilateral neglect and prospects for rehabilitation. The idea here is that in neglect, ipsilesional events invariably 'win' the competition for selection at the expense of contralesional events. Using a shape comparison task, we have shown that when ipsilesional stimulation is reduced, neglect is attenuated.

B3. Axis Based Visual Neglect: In a final study, we (with Driver) investigated what defines the contra-/ipsi-lesional divide determining the subset of information that is neglected in unilateral neglect. We report three patients with unilateral neglect who showed a deficit defined by axis-based, object-centred coordinates (2.18).

C. The Simple Reaction Time Deficit in Parkinson's Disease *(Goodrich)*

It has been widely held that performance of simple RT utilises only a subset of those processes underlying choice RT performance. Following on from the work of Frith and Done (1986), we have shown that the traditional subtractive view of RT performance is not tenable and that simple and choice RT are doubly dissociable (2.30). Using a series of RT tasks with different stimulus and response modalities, we showed that, in normal subjects, simple RT is more affected than choice RT by the addition of a secondary task. This suggests that at least part of the normal simple-RT advantage is attributable to an attentional-demanding process peculiar to the simple RT task.

Previous studies suggest that the same process that speeds simple RT in normal subjects is impaired in at least some patients with Parkinson's disease. In a series of studies (with John Harrison, Charing Cross Hospital and Leslie Henderson, University of Hertfordshire) we attempted to define the nature of this attention- demanding process. In one study, we showed that the Parkinsonian disadvantage for simple RT did not appear to be due to an inability to maintain focused attention on a single, expected stimulus. In a further study, in response to inconsistencies in the literature, we used a model-driven approach in order to isolate a subtype of Parkinsonian subjects with neurological signs of frontal lobe dysfunction who reliably exhibit a selective simple RT prolongation. In a further paper, we refuted the widely held notion that in Parkinson's disease, the simple RT deficit and the impairment shown on predictable tracking tasks stem from the same underlying disorder of preparation (2.37).

FUTURE PROPOSALS

A. Visual Attention and Extinction *(Goodrich)*

A1. Perceptual Grouping and Selective Attention: We will continue with experiments examining the relationship between (i) perceptual organisation and selection, and (ii) non-perceptual task organisation and selection. In the first category of studies, we wish to explore precisely which object properties produce an advantage for selection, and therefore, presumably, which object properties are being analysed before and/or during the process of selection. This would involve comparing rates of extinction while manipulating lower-level variables (such as whether the items formed good gestalts) as well as higher-level variables (such as the meaningful nature of the objects).

A2. Non-Perceptual Task Variables and Selective Attention: In the second category of studies, we will explore the nature of the task variables which produces the 'anti-extinction' effect. For example, in one study (with Rob Rogers, University of Cambridge) we are comparing the effects of internal versus external task priming on the 'anti-extinction' effect.

B. Identifying Factors which Reduce Unilateral Neglect *(Goodrich)*

Links have been established with the physiotherapy department, Hinchingbrooke Hospital, Huntingdon. We (with Driver) will offer supervision and ideas for research projects which would be carried out by the physiotherapists. Our proposed interventions are all driven by theories of normal attentional function. This collaboration has great potential since a direct contact will be established between experimental psychology (and laboratory based studies) and rehabilitation studies in hospital settings. Among a range of ideas for studies are the following:

B1. Intermodality Interactions: We will continue exploring the rehabilitative implications of intermodality interactions by setting up series of studies in which we attract the patient's attention to the impaired side in one modality by stimulation in another. Tactile stimulation appears to be promising; since the patient is generally surrounded by sights and sounds on all sides, vision and audition might be less efficacious. By contrast, an abrupt tactile stimulus would rarely have to compete with comparable stimulation on the ipsilesional side.

B2. Ipsilesional Capture in Unilateral Neglect: Further work will be carried out exploring the notion of ipsilateral capture and rehabilitation in a more realistic setting than in the shape studies described above. For instance, on hospital wards, the general trend is to place the patients' possessions to the contralesional side in the hope of facilitating leftward exploration. We shall not only place key information on the contralesional side of space, but also reduce the degree of ipsilesional stimulation. We will test patients performing everyday activities with and without blank screens placed on their ipsilesional side.

B3. Axis Based Visual Neglect: No future plans at present.

B4. Attentional Load and Unilateral Neglect: The degree of neglect shown by patients appears to vary with their activity. For example, neglect appears more pronounced in walking than in sitting. One interpretation is that when 'attentional load' is greater, less capacity remains to utilise strategies designed to overcome neglect (e.g. consciously scanning to the left). We will ask patients to perform a standard test of neglect in sitting and standing (and walking if possible). If neglect is greater in standing, a possible rehabilitation strategy is "WALK-STOP-LOOK-WALK-STOP-LOOK".

CONSCIOUSNESS (Marcel)

Introduction

Two main themes occupy the current investigations: (i) the unity and fractionation of consciousness; (ii) the extension of the study of consciousness to bodily experience and sensation (and to emotional experience). The approach taken in many of the studies combines theoretical and applied issues and interrelates clinical and normal populations. The applied issues include the diagnosis and rehabilitation of neurological patients and the understanding of effects of general anaesthetic in surgery. The clinical populations, while mostly neurological, also include and extend to psychiatric and affective disorders.

A. Unity of Consciousness

Most theoretical and empirical studies assume a unity of consciousness. Unity of consciousness can mean three things: (i) that there is no real distinction between first-order phenomenal experience and second-order reflexive or introspective consciousness (the source of report), or at least that the former is transparent to the latter; (ii) that each is singular and indivisible; (iii) that the contents of consciousness are integrated by mutual co-reference at any one time, and therefore that there cannot be (unnoticed) contradictions of experience. The following studies cast doubt on these assumptions and suggest (a) a real division between first- and second-order consciousness, (b) that one or both levels may be non-unitary, (c) that there can be failure of access between first- and second-order levels, and (d) that simultaneous contradictions in experience which go unnoticed do occur.

A1. Influence of Mode of Report (Marcel): Psychophysical studies with a blindsight subject and normal subjects showed essentially the same phenomenon (2.147). Subjects were asked either to guess the presence/absence of a threshold visual stimulus or to report their awareness of such presence/absence. In each condition they responded concurrently by three means: blinking, button press with finger, vocal. Accuracy was higher when guessing than when reporting experience, which suggests (according to current conventions) that report data reflect consciousness; and the guessing condition showed no dissociation between the response modes. When reporting, however, the different response modes were often in contradiction. Especially when responding fast, subjects were unaware of these self-contradictions. Conditions with each response mode tested singly and with different response delays show the same pattern. The account that is most parsimonious and yet applicable to other phenomena is that second-order reflexive consciousness may be split, in this case according to response mode, and that separate divisions may differ in their access to first-order phenomenal experience. This conceptualisation has major implications both for the analysis of psychological data, clinical and normal, and for long-standing philosophical assumptions. It is backed up by and applicable to the other studies reported in this section. Further studies, some started, will look at other stimulus modalities and the role of "stimulus-response compatibility" (see Proposals for Future Work).

A2. Unawareness of Sensory and Motor Loss: The single most predictive index of neuropsychological recovery and rehabilitative efficacy is awareness of the deficit, which is often lacking (anosognosia) in the acute phase after trauma. In addition, lack of awareness of certain types of deficit has important theoretical implications for aspects of self consciousness. Despite these two tributes to its importance, this is a largely unexplored area. In a joint British-Swedish study, we have attempted to study anosognosia for hemiplegia and hemianaesthesia in stroke patients. We have developed a successful combination of structured interview and tests for an exploratory group study, and the data indicate how it can be refined as a clinical and research tool (2.147). Results indicate that anosognosia is (i) unrelated to confusion, (ii) can be independent of degree of awareness of other deficits, sensory or psychological, (iii) is related to but not accounted for by sensory loss, (iv) is related to time since lesion (acute-chronic), (v) is unrelated to unilateral personal neglect. In addition, the study has revealed several intriguing phenomena. (i) Importantly for clinical purposes, patients may be aware of having a plegia but quite unaware of its specific everyday consequences. (ii) A number of patients show evidence of being simultaneously aware and unaware of their specific disabilities. First, a number of patients are unaware of their inability on bimanual tasks if asked "In your present state how well could you ...?", but are accurate if asked in the form "If I was in your present state, how well could I ...?". Second, some patients are unaware if asked "Is this arm (the completely plegic arm) weak?" but are fully aware if asked in the form "Is this arm ever naughty? Does it ever not do what you want ?". Apart from the interpretation that self-knowledge is sensitive to the description under which it is addressed, this suggests a kind of split in reflexive introspective consciousness. Indeed, an extension of this characterisation may be made to spatial neglect in general (see discussions of neglect in this report by Duncan, Robertson, Goodrich), where a number of studies suggest that, rather than being unaware of neglected stimuli, the patient is aware but "dissociated" from them.

A3. Unawareness of Blindness with Blindsight: One of the most intriguing, though very rare, instances of unawareness of a deficit is Anton's Syndrome, unawareness of blindness. I have been able to study such a patient in whom a head injury bilaterally impacted the occipital poles. Although he showed some mild frontal effects, the patient was not clinically confused. Also he was fully aware of his slight memory impairments and of his physical state (broken legs). Further, while he was aware, from failures in visually based behaviour, that he had some visual problems, and acknowledged frustration at this, he was not aware of being blind. Therefore his unawareness is unlikely to be an intentional denial to preserve self-esteem. His adequate visual imagery performance suggests no problem with internally generated visual experience. The impairment thus appears to be a selective failure of introspective access to lack of visual experience of the world. A highly important aspect of this case is that, while being blind on conventional direct or explicit testing, the patient appears to have Blindsight when tested appropriately. He can accurately point at and grasp objects when forced to do so rapidly. While performing at chance in making conventional confident binary judgements of extremes of luminance, he performs nearly perfectly in the same situation when asked to guess luminance level. The presence of blindsight in Anton's syndrome has never been tested until now. This double lack of awareness (loss of visual experience with preserved aspects of visual processing, and unawareness of that loss) once again suggests two levels of consciousness, and suggests that the way that we know many of our sensory and cognitive capacities is by reflexive access to specific types of phenomenal experience (seeing, feeling, recognising). In addition, this is one of the first cases (if not the first) of bilateral blindsight to be studied, which I propose to continue with the patient's willingness.

A4. Measures of Nonconscious Perception: Two approaches to measuring nonconscious perception of masked visual stimuli were investigated. According to the first, nonconscious perception is demonstrated when indirect measures (priming) are more sensitive than direct measures (forced choice discrimination accuracy). Various direct and indirect measures were compared to investigate their potential nonequivalence, and the effect of this on experimental results. Indirect measures were not consistently more sensitive than direct ones. This does not, however, imply absence of nonconscious perception, since two direct measures, forced-choice discrimination accuracy and subjective awareness of the relevant information, may be dissociated. The second approach was therefore to investigate this dissociation. Traditional criticisms of introspective report as an index of awareness were overcome by progressively more detailed questions addressing awareness of different aspects of masked stimuli. This employed trial-by-trial ratings and post-block questionnaires, but did not depend on absolute accuracy. Evidence for nonconscious perception was found in some tasks (semantic categorisation) but not in others (stimulus detection). "Passivity" of the perceiver seems an important determinant of obtaining effects of nonconscious perception. The approach provides an interpretative tool for analysing the relationship between subjective experience and performance in a variety of situations (2.176).

A5. Emotional Experience and Consciousness: An area relatively neglected by both students of consciousness and students of emotion is emotional experience. Lambie has extensively reviewed data on emotional experience and its constitutive, phenomenal and formal properties from normal, clinical and cross-cultural literatures, and has placed this in the context of theories of emotion and of consciousness. Empirical dissociations of emotional experience from awareness of other emotion components (e.g. bodily sensations) cast doubt on most existing theories. The account emerging from this study is compatible with the distinction drawn above between non-reflexive and reflexive consciousness, and implies certain kinds of pre-conscious mechanisms, e.g., attention and attribution.

A6. Summary: The above-mentioned studies, together with preliminary work on general anaesthesia (section A4, Future Proposals), can be unified in their implications. They suggest, in addition to nonconscious processing, not only a separation of first-order awareness from second-order reflexive awareness, but also the existence of dissociative states or splits in the latter, usually discussed in the context of hypnosis and post-traumatic stress. Traditionally, the condition most often suggested to reflect dual consciousness is that of split-brain (commissurotomised) patients. In a discussion paper (2.148) I have criticised some of the criteria currently used to adduce disunified or partially unified consciousness in these patients. The distinction between personal and subpersonal levels is not co-extensive with conscious and nonconscious, but is rather a distinction between levels of explanatory discourse. However the personal level is linked to consciousness in its recourse to concepts such as intention, self-reference and subjective experience. In a review paper (2.116) I have discussed how the personal level manifests itself in neuropsychological syndromes. The conclusion is that, both for explanation and rehabilitation, neuropsychology cannot successfully reduce to the level of sub-personal mechanism but must also take account of personal-level structures.

B. Bodily Experience and Sensation

Theoretical and empirical work on consciousness have paid little attention to bodily experience. Yet it is arguably central to any (non-dualist) sense of self, as well as to understanding our emotional and spatial experience. Several issues are addressed in the current work. (i) What underlies our bodily experience? While a Helmholtzian approach (nonconscious inference) is more easily seen to be applicable to perceptual consciousness of the external world, it would also appear that it is applicable to the experience of bodily sensation, i.e., the result of nonconscious inference on the basis of a spatial representation. (ii) What is the nature of the deficit in neurologically based losses of awareness of the body? (iii) What is the relationship of bodily representation in sensory experience and in action?

In addition to the empirical work referred to below, some of the context for that research is captured in theoretical work and reviews. One approach focusses on the nonconscious basis of conscious experience of our bodies and of sensation, reviewing experimental psychology and physiology, neurological syndromes, clinical (affective) research and cross-cultural studies. Our bodily experience is suggested to be the result of (i) a nonconscious structural representation (of the body as distinct from the rest of the spatial world), (ii) inference and attribution, (iii) culturally relative somatic symbolisation of self, (iv) spatially selective attention. In addition, a distinction is drawn between (a) the experienced space of sensations and of the egocentric disposition of body parts (Body Image), versus (b) the space of body parts as targets and obstacles for movements of other body parts (Body Schema). A second paper (2.117) argues that bodily experience and sensations are (explanatorily) secondary to spatial cognition and self. (i) Bodily sensations experienced as such (e.g., pressure on object from finger experienced as pain in finger as opposed to experience of mass and location of the object) depend on attention to oneself as a spatial entity, and therefore depend on a spatial self-world distinction. (ii) In different cultures, whether certain physical and emotional situations are experienced as bodily sensation or as purely mental is the result of the degree of somatization of self. This existential sense of "self" is a social construct. Much of this theoretical work has taken place in the context of an Interdisciplinary Project on Spatial Representation based at King's College Cambridge. Two edited volumes have resulted from this project. In the second, "The Body and the Self" (2.2), a jointly written introductory chapter (2.97) examines the importance of the body in the light of developmental, neurological, cognitive and philosophical work and issues.

B1. Role of Body Image and Nonconscious Inference in Bodily Experience - Intersensory Illusions and Dissociations

B1.1. Touch and Vision: The sensation of single or double tactile stimulation (the 2-point threshold) has usually been thought of as due only to, and the direct reflection of, density of innervation at the skin. In a series of experiments (2.77) double, disparate retinal images of a stimulated finger were produced by subjects focussing visual attention on a display two metres beyond the finger. In this situation, although requested to attend primarily to touch, subjects experience double tactile sensation to a single touch, the effect diminishing in subjects with greater ocular dominance. It is suggested that one's conscious access to a modality (touch) is not direct but via a level of representation (body image) affected by other modalities (e.g. vision). This is paralleled by other sensory interactions, e.g. visual-vestibular in experience of self-motion. This work is now completed.

B1.2. Location and Shape of Body Parts: Replications and extensions have been carried out of the effects of vibrotactile muscular stimulation (biceps or triceps). (a) If the forearm is held in a rest during stimulation, it feels to have moved in a direction opposite to that in which it would have moved if left free. If the finger is in contact with another part of the body, then that part of the body is felt to have grown or receded appropriately, e.g. the nose feels to be growing. This latter effect is difficult to account for without the notion of nonconscious inference. (b) If subjects cannot see the stimulated arm, their verbal reports of the position of the hand of the stimulated arm reflect the primary vibratory illusion. However, if subjects are asked to quickly grasp the hand with their other hand, they do so correctly. If the grasp is delayed, subjects are more likely to reach to the illusory position. This is interpreted in terms of the distinction between a nonconscious Body Schema, whose spatial representation of body parts modulates immediate spatial coordination of the body, and a conscious proprioceptive Body Image of the space of sensations and body part disposition. Body space is coded quite differently in these two representations. If a body-directed movement is delayed, the specification of target location becomes increasingly subject to its coding in the conscious Body Image.

B2. Somatosensory and Motor Imagery and Experience of Manual Posture (Marcel, Bisiach, Johns, Berti, Ladavàs, Pizzamiglio): The context for these studies is that (a) patients with unilateral personal neglect are sometimes thought to have lost part of the representation of their bodies; (b) patients with hemiplegia or hemianaesthesia (unilateral loss of movement or sensation) due to stroke might be thought to be unable to have somatosensory or kinaesthetic imagery for the affected body parts (on the basis of the idea that perception and imagery share common representational bases). In the first part of our studies, latency patterns suggested that normal subjects identify rotated photographs of left and right hands via rotation of perceptual and motor images respectively for dorsal and palmar views (cf. Shepard & Cooper, 1982). This was confirmed by the effect on latency patterns of selective interference tasks (e.g. maintenance of pressure by one hand in a fixed position). The same patterns of data were obtained when the task was given to right-brain-damaged patients with and without hemiplegia, with and without hemianaesthesia, with and without unilateral personal/bodily neglect. The patients showed no difference in data patterns for photos of left and right hands, but when the same interference task as in normals was applied to their unaffected hand, they showed the same selective interference effects as normal subjects, i.e. patterns of identification latency for the affected hand were uninfluenced. The results suggest (i) that patients who seem phenomenally unaware of a limb, or who lack movement or sensation in it, can nonetheless manipulate a motor or perceptual image of that limb; (ii) that in somatic and motor imagery, just as in visual imagery, spatial representation and processing should be distinguished from phenomenal experience; (iii) that bodily neglect does not involve loss of the representation of the neglected body parts. At the time of writing, publication awaits completion of testing of control groups of brain-damaged patients. The data on normal subjects have been written up by Marcel and Johns.

B3. Unawareness of Sensory and Motor Loss (Marcel, Tegnèr): The work reported in section A2 as bearing on the fractionation of consciousness is clearly also highly relevant to bodily experience. Taken together with the study of pain in general anaesthesia (section A4. of Future Proposals), the apparent "split consciousness" suggests that bodily sensations (or their lack) may have phenomenal status even if we are not attending to or aware of them. The immediate practical implication of this work is that the actions that may be attempted by plegic or anaesthetic stroke patients are not constrained by their reflexive awareness of their sensory or motor capabilities, i.e. general awareness of deficit does not prevent patients attempting impossible actions. Therefore extra care is required in rehabilitation before early discharge.

C. Motor Control - Influence of Intention on Accessibility and Fluency of Action *(Marcel)*

In Ideomotor Apraxia, actions which cannot be produced on request or by imitation are often produced or improved when performed as a component of normal activities. We have explored the extent of occurrence of such phenomena in a range of neurological patients, one application being identification of appropriate eliciting conditions for therapy. Patients showing the phenomenon were filmed in a variety of situations. Dual-task conditions (appropriate to each patient's impaired behaviour) suggested that, in general, the performance difference is not due to "over-attention". When an activity was induced of which the relevant behaviour was a component, improvement was obtained in all cases. Unexpectedly, a further significant improvement was observed when the action had social or personal significance (e.g. (i) lifting and moving a cylinder; (ii) drinking a tumbler of liquid; (iii) offering mugs of tea to guests). These findings suggest that motor control is strongly influenced by the nature of the intention. This should be exploited where possible in choosing appropriate situations for eliciting and retraining of motor acts. This work (2.116) is completed and is not being continued.

PROPOSALS FOR FUTURE WORK

A. Unity of Consciousness

A1. Influence of Mode of Report - Psychophysical Studies in Normal Subjects: The first set of studies on the influence of Mode of Report (see A1. above) all used visual stimuli. It is important to examine the effect of e.g. tactile and auditory-verbal stimuli, in order to see if the observed differential sensitivity of response modes is in any way due to stimulus-response compatibility. Since selective response-mode preparation may also play a part in differential sensitivity, it is important to examine conditions where the required response-mode or order of response-modes is indicated by a post-stimulus signal.

A2. Unawareness of Sensory and Motor Loss: There are two extensions planned for the work on anosognosia for hemiplegia and hemianaesthesia.

A2.1 The degree of interest shown in this work means that it would be useful to develop our battery of tests into a clinical and research tool. For the former purpose it requires shortening, since at present it takes at least 40 minutes to administer. Our current analyses are already aimed at selecting the most interesting tests and questions. For the latter purpose, in addition to selecting the most significant tests and questions, we need to standardise and validate to some degree. Since our control groups consisted of normal subjects of different age-ranges, some of this work is already done.

A2.2 We plan to carry out detailed single case and experimental studies of stroke patients anosognosic for hemiplegia and hemianaesthesia who show dissociations of awareness of their state. The phenomena indicated in section A2 suggest that such dissociations are linked to aspects of selfhood and to social and emotional aspects of questioning. We envisage enlisting clinical psychologists to aid design of studies to illuminate these phenomena and to provide rehabilitative heuristics.

A3. Bilateral Blindsight: The patient with both unawareness for blindness and blindsight has now recovered awareness of his phenomenal blindness. However, he is now left with bilateral blindsight. This is an important case to study since no study of blindsight has yet been carried out on a case with full visual field loss. Scattered light can no longer be appealed to for explanation. More importantly, several well-established blindsight phenomena may depend on the visual experience from remaining fully intact parts of the visual field.

For example my own (2.78) and other researchers' studies have shown awareness of static stimuli in the blind field provided that appropriate stimuli are presented simultaneously to the sighted field (usually an intact hemi-field). Would the same effects be obtained if both fields are phenomenally blind but with blindsight?

A4. Awareness of Pain in General Anaesthesia: Certain techniques used in short gynaecological operations provide a rare opportunity to study consciousness under general anaesthetic. When the fallopian tubes are clipped by laproscopy, occasionally three conditions obtain: (a) the patient is tilted slightly head-down so that the viscera can be pushed to rest on the diaphragm while the abdomen is inflated; (b) the musculature is neither paralysed nor fully relaxed, reflex movements being used by the operating team; (c) when possible, the patient is not artificially ventilated. Under such conditions it is sometimes possible (physically) for the patient to talk. In pilot studies at the John Radcliffe Hospital, Oxford, we have attempted to ask such patients during the operation if they experience pain, and, if so, where. Three important phenomena have emerged. Even when patients show no general signs of awareness, while many patients make no response, some (c. 40-50%) do respond vocally. While some of those responding report no pain, others "correctly" report pain in the chest. Since very few know how the operation is conducted they would hardly expect pain in the chest. Most intriguingly, a few patients who at first report no pain, do so when asked a further question derived from studies of hypnotic analgesia : "Does any part of you experience any pain ?". A small number of women have responded "She has a pain in her chest (and/or groin/stomach)". This response, especially use of the third-person (she), suggests a dissociative state of split consciousness, and that the functional effect of certain types and levels of general anaesthetic is similar to that of hypnosis. It must be emphasised that these are as yet pilot studies. Parametric studies of anaesthetic level and type as well as of behavioural and physiological indices are clearly needed.

A5. Theoretical Work on Self-Consciousness: Following the success of the Interdisciplinary Project on Spatial Representation (1989-93), a group of philosophers and psychologists intends to collaborate on a similar venture on Foundations of Self-Consciousness. Among other themes, this project will focus on the relation between bodily awareness and self-consciousness, on foundations of autobiography as transtemporal selfhood, and on social and emotional bases of self-consciousness. The British Academy have shown interest in supporting such a project. At the moment the core collaborators include Marcel, Naomi Eilan, John Campbell, William Brewer, John O'Keefe and Josef Perner. However a number of other scientists and philosophers have shown a keen interest.

B. Bodily Experience and Sensation

B1. Role of Body Image

B1.1 Location and Shape of Body Parts: The different effects of vibrotactile stimulation on the experienced location of a body part and on its location as a target for movement were interpreted in section B1.2 (current work) to suggest different spatial coding for sensation and motor control. This can also be seen as a difference between the conscious and nonconscious spatial aspects of intentions for action, e.g. location versus movement paths. When the current work is completed, I propose to investigate this as follows. The stimulated arm is visually occluded by a horizontal board on which light-emitting diodes are distributed. After initial vibrotactile stimulation, illumination of one L.E.D. indicates a target location. The subject either (a) has to move hand of the the stimulated arm to a position beneath the target or (b) has to draw the direction and extent of required movement of that hand with the other hand. Degree of influence of the sensory illusion and dissociation of the two measures should distinguish the sensory-versus-motor hypothesis from the intention-coding hypothesis.

B1.2 Role of Body Image - Structural Divisions: A new line of work is planned on this topic. Several types of evidence suggest that a nonconscious structural description of the body underlies the spatiality of experienced bodily sensations. It is of relevance to explaining certain phenomena whether such a description explicitly represents structural segmentations of the body, e.g. divisions at mechanical articulations. Two types of study are proposed. In the first, it is predicted that sensory discriminations will be greater across putative segment boundaries than within segments (equal separations of tactile stimuli across the wrist versus within the forearm or hand). In the second type of study, it is predicted that tactile priming or tactile aftereffects will be more effective within a segment than for equal separations across segment boundaries. Such effects would cast doubt on certain theories of spatial attention in bodily sensation (e.g. Kinsbourne, in press) which postulate no representation of body space as distinct from external space. They would also illuminate certain topological phenomena in peripherally demyelinized patients (see B2.2 below).

B2. Demyelinization and Proprioception (new work): Patients who, through peripheral neuropathy, are deprived of almost all afferent information carried by fast, myelinated nerves provide a unique opportunity to study several issues applicable to normal people. The main patient to be studied is IW (already partly studied) who from the neck down is assumed to have no kinesthetic or proprioceptive information and has lost all corresponding (conscious) sensation except deep pain and temperature at the surface. Several other patients have been traced abroad and one (GL, Montreal) has been partially studied.

B2.1 Tactile Sensation and Kinaesthesis: Absent, Reduced, or Nonconscious?: At present the only psychophysical studies of sensation carried out on I.W. have been by report. We intend to use forced-choice techniques. We have started this and already found evidence of some somatic "blindsight". This is important since otherwise it remains a mystery how IW has retaught himself to walk and reach without constant visual guidance. It also suggests additional different psychological roles for fast and slow afferent pathways similar to those for cortical and tectal pathways in vision.

B2.2 Location of Sensation in Body Parts: IW knows proprioceptively in which part of his body a pain or temperature stimulus is but does not know where the body-part is in egocentric space. However, preliminary studies suggest that this experienced location of sensation is only topographic (in the forearm versus hand) but not determinate (where in the forearm). It is possible that it is dynamic information (which he lacks) that provides such determinate information, a view suggested by pre-existing studies by Brouchon and Paillard. This work will involve experiments on IW and on normal subjects involving location of sensation at different time delays after passive and active movement.

B2.3 Coding of Location of Stimuli in Peri-Personal Space: Since IW is sensitive to temperature, we can produce non-visible somatic stimuli (heat spots) on a surface. Comparison of his learning of (a) the egocentric locations and (b) configural relationship of such stimuli when he can see his arm movements and when he cannot should help to illuminate the relationship between topokinetic and morphokinetic spatial coding.

B2.4 Distinguishing Self-Movement from World-Movement: IW's pain receptors provide a non-painful sensitivity to certain types of texture (e.g. stiff bristles of a scrubbing brush). We can thus assess the role of reafference in distinguishing one's own from the world's movements by comparing three conditions (blindfolded): (i) self-generated movements across an appropriately textured surface (stiff brush bristles), (ii) self-generated movements with no relative movement of tactile texture, (iii) passive movement of his hand across the surface, (iv) movement of the surface across his hand held steady by the same means used to move it in the second condition. This provides a new way to test the Von Holst and Mittelstaedt account of perception of self-movement (comparison of reafference with motor copy), and to evaluate the relative contributions of corollary discharge, movement reafference and tactile flow-field.

B2.5 Balance: IW used to fall over if he did not visually monitor himself or focus on a vertical surface. He no longer has this problem. Use of Wing's balance board in different attentional conditions may identify the mechanism or strategy he has evolved in his self-rehabilitation, and thus help in the physiotherapy of similar patients.

NATURALISTIC STUDIES OF ACTION SLIPS *(Sellen)*

Introduction

Slips can be modelled as a dissociation between a conscious, intentional system and unconscious, automated action. The characterisation of slips as "liberated automatisms" has benefitted from collections of naturalistic errors from which taxonomies of error have been derived (e.g., Norman, 1981; Reason & Mycielska, 1982). Sellen's theoretical work on action slips has also focused on the analysis and categorisation of naturalistic error corpora, collected mainly through diary studies and other methods of self-report (summarised, in part, in Sellen & Norman, 1992). The first area which Sellen's work has addressed is that of detection of everyday action slips. The second area is more applied and specialised in nature, focusing on slips committed by anaesthetists.

A. Detection of Action Slips

The evaluation of action and the detection of slips have been largely ignored in the psychological literature. In an initial exploration of the possible underlying cognitive mechanisms (2.60), a corpus of over 500 everyday slips and mistakes was collected by asking subjects to keep a diary, focusing on the details of error detection and identification. The errors constituted a diverse set, from slips at the sensorimotor level, to memory lapses, to errors in judgement. The tasks involved were "everyday" tasks and were thus also diverse, spanning a wide range of human daily activities.

On the basis of this collection, a theoretical taxonomy of detection modes was proposed, consisting of three broad categories: Action-Based detection, Outcome-Based detection, and detection through Limiting Functions. Action-based detection describes errors detected by comparing incipient action, executed action, or memory of action to an internal reference. Errors detected on the basis of outcome describes detection which results from observation of the consequences of action as they are manifest in the external world. Detection by a Limiting Function describes errors detected because constraints in the external world prevent further action. Each category or "mode" of detection has implications for the kind of feedback used in realising an error, and in the reference against which the feedback is compared. The taxonomy provides a general, descriptive framework for understanding these various mechanisms, and the cognitive levels at which they operate.

B. Errors in Anaesthesia

The psychology of human error was applied to the problem of errors in complex tasks, such as the job of an anaesthetist (2.59, 2.62). In collaboration with anaesthetists at the Royal Adelaide Hospital in South Australia, work began by helping in the re-design of a form for anaesthetists to provide anonymous report of "incidents" which occurred on the job. An incident was defined as any accident or error, whether or not it could have been prevented, and whether or not it had detrimental effects. This study, called the Australian Incident Monitoring Study (AIMS), has so far resulted in a corpus of over 3,000 incident reports.

Initial analysis of these reports identified a range of factors which contributed to the incidents, from workplace policies and procedures, to equipment and product design. The nature of the errors that actively contributed to the incidents were also classified according to whether there were problems in knowledge and judgement, misapplication of rules, or slips due to habit or inattention.

The next phase of the research involved the initial classification of the incidents into subsets of interest. One such subset was defined as those incidents in which drugs were inadvertently swapped. Analysis of the causal and contributing factors underlying "wrong-drug" errors identified distraction and haste as the two most common factors (2.16). Closer analysis of the errors suggested that most of the incidents were in fact due to simple slips, as opposed to errors resulting from bad judgement or inexperience, and an initial approach was given for the prevention and management of such slips.

FUTURE PLANS

Work on analysis of the AIMS data has only begun. Dr. John Russell, an anaesthetist at the Royal Adelaide Hospital, will be visiting the APU in the summer of 1994 in order to carry out further analysis and classification of the AIMS data. We will be collaborating with Prof. John Senders, an expert on human error, and Dr. David Duthie, an anaesthetist at Papworth Hospital. Roy Patterson from the APU will also be helping to analyse those incidents in which auditory warnings were reported to be a contributing factor. The hope is that we will be able, as a team, to outline a variety of practical ways in which errors can be prevented or managed, from the redesign of anaesthetic equipment, to suggestions for the implementation of hospital procedures and policies. In the course of this analysis, we also hope to learn more about the nature of human error in complex tasks. Errors in anaesthesia have much in common with errors in other kinds of situations, such as nuclear power plants and aeroplane cockpits. One focus of the research, about which little is currently known, will be "collaborative errors", or errors in which more than one person is involved.

In addition, we are planning a study at Papworth Hospital with eight trainee cardio-thoracic anaesthetists. The trainees will be given palm-top computing devices into which they will be asked to enter a log of anaesthetic incidents that they observe or participate in, over the course of two weeks. This should provide a more complete record of the errors that occur in the anaesthetic domain, and a more accurate estimate of their relative frequency than AIMS can deliver. We hope that the study will also begin to raise awareness of potential errors in this field, and will lead to the establishment in Britain of a reporting system similar to AIMS.

COGNITIVE CONTROL AND INTEGRATED MENTAL ACTIVITY IN COMPLEX TASKS *(Barnard, Blandford, May)*

Introduction

If we are to develop forms of cognitive theory that are readily applicable in the context of complex tasks, these theories must have a number of capabilities. First, they must, of course, adequately capture and predict regularities in cognitive behaviour. Second, theories that provide an integrated viewpoint would be of significant benefit. They avoid the problem of having to deploy different theories and techniques to analyse the many issues that arise in a typical applied context. Third, there must be a practical means of communicating and delivering the theory into that applied context. Fourth, the specific part played by cognitive theory must be clarified -- particularly in interdisciplinary contexts where theories and concepts of fundamentally different types all have "something to say" about how issues should be resolved.

For this area, the development of applicable cognitive theory is based upon the Interacting Cognitive Subsystems framework (ICS). In the previous reporting period (1986-89), ICS was applied to human-computer interaction in the context of simple command and menu based systems. The research emphasis was on the acquisition by novice users of the conceptual structure and lexical content of the dialogue tasks. Over the course of the last five years, the emphasis has been upon extending the scope and applicability of the ICS approach. One extension has been to provide a more systematic treatment of learning that goes beyond the novice user. Another key extension has been an examination of visually rich settings, including multimedia and multimodal forms of interaction. Both have contributed substantially to the development of integrated theory.

The basic extensions to the approach have largely been accomplished with intermittent internal research assistance (A. Green, Tweedie & Scott) or by graduate students (Duff & Lee); the consideration of theory application in an interdisciplinary context has had more substantial post-doctoral support through two successive rounds of Esprit Basic Research funding covering the period 1989-1995. This project, AMODEUS , has supported the work of A. Green, Blandford & May for this area and that of Whittington & Blandford (see R. Young's section of this programme). The project has been scientifically and financially co-ordinated by Barnard. It has supported around £2M of international research effort covering collaborations between two dozen scientists working in seven countries. Its core aims have been to develop modelling techniques; to examine how their outputs might best be integrated; and to consider the transferability of the techniques to real design contexts.

A. Cognitive Control in the Longer Term Development of Knowledge and Performance

Some empirical work on longer term learning was conducted prior to the current reporting period. That work has now been both summarised (2.120) and extended in a number of new directions. Much laboratory research on human-computer interaction has been "over-focused" upon the performance of novices. The work reported below goes some way towards the provision of a more balanced focus of effort. The unifying theme has been theoretical and empirical work examining the use of different forms of mental representation in complex tasks as skill develops from novice, through intermediate, to expert status.

Duff initially examined how novices and expert users dealt with the problem of using an unfamiliar digital watch, observing that the two groups resolved the uncertainties of what action to perform in rather different ways. He went on to manipulate the form of knowledge that might help to reduce uncertainty in action specification in a range of device control tasks (2.161). These included exploratory learning, learning based upon sequential procedures, and learning based upon the provision of propositional knowledge about the way the device worked. These all produced different patterns of performance and different forms of transfer when new tasks were introduced (2.19, 2.94; Duff, 1989). Duff was able to make use of ICS, and its associated analysis of uncertainty within propositional representations, to make the counter-intuitive prediction that the provision of more knowledge does not necessarily lead to a greater or more persevering reduction in uncertainty - a prediction which was supported by his data (2.161). As a part of the AMODEUS project, A. Green also made direct use of ICS and its derived analysis of the resolution of item and order uncertainties. Green took a series of specific examples from classic work on novice and expert problem solving performance, in the domains of physics and mathematics, and related them to a series of examples from the HCI literature, including the experiments of Duff. In an encouraging demonstration of the potential generalisability of theoretical concepts derived from HCI research, Green showed that both forms of "paradigm" were open to a common theoretical understanding (2.31).

Lee (2.171) developed several paradigms for studying the development of knowledge and performance in interactive tasks. In a broadly similar approach to that taken by Duff, Lee compared the methods used by novice, intermediate and expert users of a commercial word-processing system. Each developed a characteristic, and often stable, pattern of method utilisation. The most efficient functions were frequently under-utilised. In an ingenious experimental manipulation, Lee showed that providing knowledge of how functions worked was not in itself sufficient to change the patterns of usage. However, providing users with knowledge of how to reformulate the problem to make its representation compatible with their mental representation of the computer function did cause users to shift to a more efficient pattern of function utilisation (2.44). Once again the specific form of representation appears to have a crucial effect on what is learned and the dynamics of its processing. In a series of studies with strongly visual (menu) interactions, Lee showed that users acquire specific forms of knowledge that reflect the uncertainties they have had to resolve in the development of task representations (2.45). Following leads in the literature on the causes of error, Lee was also able to show (2.43, 2.171) that certain forms of "action slip" have a high initial incidence which reduces as users acquire more experience. However, with even greater experience the incidence of the same type of errors actually increases again. Such a change may well reflect a qualitative shift in the pattern of cognitive control from one with a focus on the acquisition of the interface task itself, to a pattern of cognitive control more typical of a focus on the underlying domain of work (in this case, stock market trading).

B. The Representation of Visually Rich Environments and Dynamic Deployment of Attention in Complex Tasks

Most theoretical contributions in the area of human-computer interaction stress the importance of some form of task representation. Although there have been modest extensions to task based approaches to help deal with visually rich interactional settings, this tends to be accomplished by adding features to the task representation. Interacting Cognitive Subsystems assumes distinct types of mental representation. It is assumed that task representations are generally held in a semantic form, but that these are processed in conjunction with two visually based codes: a raw visual code and a higher level structural description of items in an object-based code. Since the processing of visual scenes and the deployment of attention is fundamentally dynamic, an analysis was developed based upon an analogy with thematic processing of language. Halliday's systemic grammar was taken as a point of departure. Entities in a visual scene are assumed to have a psychological subject-and-predicate structure associated with them. The mental representations constructed and manipulated then reflect the form and content of the information processed from the scene on the basis of thematic transitions among superordinate, basic and constituent units of object representations (2.51).

This approach enabled the modelling of the deployment of visual attention to be brought together at an object-based level with both bottom-up influences of the visual scene and top-down influences of the task. Initial experiments (2.32) suggested that search time in an array was related to: (i) the complexity of the predicate structures; (ii) the number of items in the scene at a given level of structural decomposition that shared the same psychological subject (similarity); and (iii) the extent to which the task and setting forced thematic changes in dynamic processing that required the encoding of particular elements of the structure. People do not need, for example, to encode the visual details of items that are always presented in the same physical location. Quite detailed predictions based upon this model have been supported by the results of further experiments in icon search tasks (2.52). The form of analysis is by no means restricted to simple search tasks. It has now been applied to several concrete design issues in complex displays in many different applications (e.g. see 2.50, 2.79, 2.149, 2.154, 2.155). The potential for inter-relating task-based properties to the use that visual information is put also reinforces the scientific message from the work of Wright (detailed under the Language and Communication Programme).

The work on structural descriptions of visual form was initiated by May & Barnard during the first AMODEUS project. During the second project, it has been extended to multimedia and multimodal settings for interactive performance. As a part of the requirements for European reporting, detailed papers have already been produced on the application of the analysis to film theory and dynamic video-clips as well as the cross-modal blending of data streams involving vision, dynamic gestures and voice (e.g., see 2.151, 2.152 which include 2.84 and 2.173). The results of initial experiments are also encouraging. In a setting which experimentally simulated key aspects of some computer-supported work environments, video sequences were shown of an actor making deictic reference (hand gestures) to a task-based array of items. Consistent with earlier generalisations, performance in this complex setting depends upon the extent to which the gestures eliminate uncertainty of item identity and location (2.69).

C. Approximate Modelling of Cognitive Activity and its Application

A large proportion of the cumulative empirical work carried out by Barnard and his colleagues has been oriented towards the longer term theoretical objective of developing modelling tools. The core idea is that production system technology, embodying psychological principles, could be used to generate approximate models that describe mental activity in complex tasks. These theoretical descriptions could then underpin the processes of both scientific prediction and design analysis. At the end of the previous reporting period the general concepts had been outlined and a number of local examples implemented in a running expert system (reviewed again in 2.81 and 2.82). ICS formed the theoretical basis of approximations that described basic configurations of mental processes; the procedural knowledge embodied in those processes; the memory records used; and a characterisation of dynamic cognitive control. Descriptions in this attribute space were generated by explicit rules and were themselves operated on by explicit rules to generate predictions or design advice (see Barnard et al. 1988).

For the first AMODEUS project, a target was set to generate a modeller capable of dealing with a broad range of settings. The technical work of specifying the detailed theoretical constructs needed for this implementation was extensive (2.84). It involved not only the basic theory, but also how best to scope the approximations over conceptual phases of mental activity (goal formation, action specification and action execution) and longer term learning (novice, intermediate & expert). Naturally, the specification drew upon much of the work reported above and in previous APU progress reports on this topic. By the end of the project a running modeller was produced embodying several hundred rules. The software and its associated documentation and evidence of performance (2.153) was delivered to the CEC as a scientific deliverable (associated with 2.154). The final system was capable of addressing seven areas including experimental topics covered in the last progress report (lexical command and task structures); experimental work covered in the previous two sections (2.19, 2.32); and a range of practical scenarios drawn from HCI design problems (e.g. 2.51). Key developments in the modeller, not previously reported in the literature, and the underpinnings of its generalisability have now made their way through to journal publication (2.50). Further work on re-implementing the modeller is currently underway (see 2.152).

D. The Application of Modelling in Design and Interdisciplinary Contexts

A central objective of the second AMODEUS project has been to investigate how theoretical techniques might best be transferred to, and deployed in, the context of design, software development and usability evaluation. A number of different strands of research have again been pursued.

Much emphasis has been placed on using modelling techniques in the context of concrete design scenarios. This itself involves ensuring that theoretical analyses have relevance and appropriate scope for application -- itself a matter of some methodological debate to which APU has recently contributed (2.66, 2.122 see also R Young's section of this programme). May & Barnard (2.79) have drawn together a number of scenario analyses to illustrate how ICS-based concepts of approximate modelling can provide conceptual support for the resolution of practical designs and their evaluation. As a part of the AMODEUS project, the problems of transferring both ideas and the specific tool have been the subject of systematic research. For obvious reasons of maintaining independence, these studies of transfer and tool use have been conducted by our collaborators rather than ourselves. Journal publications by others are about to appear detailing both the general nature of the transfer problems associated with ICS-based modelling as well as issues associated with the specific use of the expert system. So, for example, Buckingham-Shum & Hammond (in press) have recently reported a study in which they had human factors students attempt to apply the expert system tool, developed in the first AMODEUS project, to a specific design problem within its scope. They found that the students could make use of the tool without necessarily having a deep understanding of the underlying ICS theory. It was nonetheless clear that effective deployment did rely upon the tool user knowing all about the allied structural description techniques for tasks and displays.

As with most of the other areas of APU's work dealing with attention and cognitive control, the theoretical ideas and tools outlined here must be put to use in an interdisciplinary context. Interdisciplinary work is challenging because different disciplines make use of different terminologies, have different bases for their theoretical ideas and assign very different priorities to the resolution of specific points in a given problem space. In the specific context of human-computer interaction research, there are cognitive resource-based models, knowledge-based cognitive models, embedded user models, abstract task models, domain models, design space representations, formal models of the computer system, structured human factors methodologies, heuristic evaluation and so on. Quite clearly, they cannot all be used to analyse all issues. The problem of context sensitive selection of tools and techniques itself needs to be addressed, as does the allied problem of ensuring that the owners and advocates of individual approaches actually understand one another.

A new approach to these issues is being developed by Barnard, Blandford and Harrison. The approach makes use of formal logic to specify abstract properties of interactions among agents operating in some specified domain of application. The agents may be of any type - human or computer. As with conversational analysis, the focus of the modelling is upon the conjoint sequential behaviour of the relevant agents. Interactional events are defined, as are the constraints upon their sequential organisation. Such constraints may deal with properties like detours in trajectories, the disengagement of individual agents from the interaction, or issues of interactional focus (2.70, 2.85, 2.142, 2.143). This provides a means of defining design requirements - not individually for the system component or the user component but upon the whole "interactional trajectory". The requirements are initially specified at a high level of abstraction, and as they are successively "refined", the properties of the refinement highlight specific needs for detailed models and evaluation techniques.

The cognitive implications of these interactional analyses can be very direct. So for example, section A.1 above referred to an action "slip". An example is that of a computer user attempting to perform an action in an unselected window. Interactional analysis of this setting indicated that the transitions between users' cognitive states and the corresponding system states (how the display indicates that a window is active) were not reflected in the interactional trajectory. A principle was therefore proposed to mark interactional transitions by separate "interactional" events. This was then refined to the levels of user and system properties. The idea was to make the window border have a "dynamic or fizzing" quality at readily definable transitions - when users or system appeared to disengage from continuous interaction or change focus within it. Experiments incorporating this way of governing dialogue transitions produced dramatic reductions in the rate of action slips (2.43, 2.124). Furthermore, it was not simply a matter of the fizzy border having more attention grabbing properties throughout. People do adapt to the continuous presence of such properties. Empirical tests have confirmed that, to have its full effect, the property must be active only during an interactional transition (see Ch. 4 of 2.171).

An unanticipated research thread has emerged through this interdisciplinary collaboration. The above analysis works via a top-down specification of the requirements on the interaction. The initial assumption was that when refinement reached a point where the properties of interest dealt solely with a cognitive or system agent, then further analysis would rightly lie in the province of a specific form of cognitive or system model. However, using our more informal definitions and specifications (2.84), the formal modellers of computer systems, on their own initiative, have recently sought to develop specifications of the ICS model of the human information processing system. This has been done by modelling key ICS axioms using a deontic extension of modal action logic. In this way properties of a cognitive model can be specified in the same terms as the model of the computer system. In principle, this should support bottom-up inferences concerning the properties of interactions (2.162, constituent part of the D7 scientific deliverable associated with 2.152). In the longer term this development has far wider potential. It offers the exciting prospect of being able to provide precise means of establishing the consequences of cognitive theory without using simulation.

E. Getting the Message Across

As with previous periods, considerable effort has gone into disseminating and summarising our research for different purposes. One is to present longer chapters for the research community to draw out issues that cannot easily be expanded upon in individual research papers (2.81, 2.118, 2.120). Another is to provide tutorial material for non-specialists in research. One overview was initially directed at human factors students (2.82), was then incorporated into a book chapter designed for electrical and software engineers (2.80) and reprinted a third time in a book oriented to the large US market for computer science students and HCI professionals. In interdisciplinary and multinational research projects the provision of short summaries assumes particular significance (2.179). A series of summaries of AMODEUS cover well in excess of 200 technical reports, software artifacts and publications (2.123, 2.150, 2.151, 2.152, 2.154, 2.155). A book has been edited with the specific aim of bringing together basic and applied material for an interdisciplinary audience in the European computing and telecommunications industries (2.3).

Two new developments are noteworthy. First, Barnard, May and Tweedie have been developing interactive technologies for presenting information. They have explored combinations of textual, animation and video technologies for communicating the products of research. Animation techniques have been developed for explaining dynamic information flow in the ICS model (2.177). Coupled with interactive presentation technologies, the resulting software has been used to support public talks. The basic technologies and techniques have been described in 2.179. The same techniques were used by May (2.172) to demonstrate dynamic perceptual phenomena and theoretical explanations. This interactive document is available in electronic form over the internet - which reflects the second major development in information dissemination (anonymous File Transfer Protocol - or FTP).

The AMODEUS project now makes the bulk of its non-copyright research material available electronically through anonymous FTP. In the first 18 months of its operation, some 100 documents have been made available in this way and 2,835 copies of them have been taken electronically by 139 sites from 25 different countries. Whilst these new developments will not draw effort away from the production of traditional refereed contributions to the archival literature, it will certainly enhance the scope and rapidity of information exchange and impact. Unlike academic journals, the network can do much to make research material easily accessible by commercial sites.

FUTURE PROPOSALS

Introduction

Over the course of the last three years, Barnard has begun to alter the balance of his research interests (see the work reported and proposed under the Cognition and Emotion programme). Since the mid seventies, the specific topic of human-computer interaction (HCI) has played a pivotal role in his research. It has provided tightly constrained topics for empirical and theoretical enquiry. It has also, of course, provided a more or less continuous supply of additional resources in the form of five research grants. Barnard's approach has involved a blend of theoretical, AI, and experimental work in the context of leading edge technological applications. This particular blend can now only really be sustained within large collaborative interdisciplinary teams. As a part of the re-balancing of effort, Barnard will discontinue managerial involvement in large scale externally funded projects in HCI. The dependence of the research programme upon direct links to leading edge technology and the application of psychological theory in this context will be reduced accordingly.

Three proposals are itemised below. These draw upon the same types of techniques as previous work and it is intended to continue work on the same general areas of the programme on attention and cognitive control. The proposals are no longer organised around external projects in HCI but upon the development and application of the Interacting Cognitive Subsystems framework (ICS). The first proposal nevertheless covers the consolidation of prior work on HCI. The second covers two related approaches to the specification of cognitive theory. One involves the embodiment of theory in AI systems for reasoning about cognitive activity and the other will explore the use of formal methods to specify abstract properties of ICS. The final proposal encompasses three topics for empirical investigations. One topic concerns the relationship between central functions and the dynamic processing of complex visual scenes, including the allocation of attention within such scenes and the use of memory resources to connect scenes. A second topic concentrates upon cross modal blending of visual and auditory information. The third topic is focused directly on unpacking cognitive control aspects of central executive functions - realised within the ICS approach as reciprocal processing of schematic and propositional meaning. These three topics share two underlying themes. They are all directed at examining exchanges among different forms of mental representation within the ICS framework and hence the integration and control of cognitive activity. Within that overall pattern of activity, all three topics are concerned, in one way or another, with the definition, and selection, of coherent streams of mental data.

A. Consolidation of HCI as a Case Study in Applied Cognitive Psychology (Barnard, Scott, May)

Much of Barnard's work on human computer-interaction has been carried out in the context of externally funded projects. The AMODEUS project is scheduled to submit its final report in the summer of 1995. Accordingly, substantial effort will have to be devoted to reporting current work throughout the first half of the next reporting period.

Barnard has for sometime been working on a larger synthesis treating most of his previous work in HCI as case study in the development and application of applied cognitive theory. The outline synthesis was presented as an invited address to the BPS Cognitive Section Meeting in 1993. A research monograph has been in preparation for sometime, and a large proportion of the material is already summarised in the form of interactive text and demonstrations (2.177). The end of the AMODEUS project should see the finalisation of a few remaining empirical, conceptual and demonstrational links. The existing monograph material will then be revised and completed.

Work in progress should also enable us to complete some tutorial aids for students of human-computer-interaction. The existing multimedia software has already been used on the MSc course in HCI at University College, London. Over the course of the next eighteen months, the software will be revised to allow students to use it individually without a tutor. It will also be supplemented with specific instructional material on the analysis of mental representations, and further worked examples of analyses carried out in AMODEUS on concrete design problems. Some of this work may be carried forward through a long-standing collaboration with Jørgensen in the psychology department at Copenhagen University. It is important to note that what is being proposed is not a major software project. We currently have the multimedia tools and expertise in their use (Jon May), to produce revisions and updates very quickly.

B. The Specification of Cognitive Theory *(Barnard, May)*

An enduring set of issues for psychology revolves around the problem of specifying theory. Much interesting and important theory still relies upon verbal presentation and relatively informal means of arriving at a prediction. Other theory can be very explicit - calling upon mathematical modelling techniques, or symbolic, connectionist or hybrid forms of simulation. Many such paradigms are both widely applicable and very powerful. However, tractable simulation usually involves a restriction in scope and requires additional assumptions about knowledge representations to be bound into the simulation. Typically these additions are not in themselves part of the formal theory. As Fox et al. (1992) have pointed out, this makes it hard to separate out the contribution of the core theory to the behaviour of the simulation. They have stimulated new debate by advocating a role for abstract specification of the core theory and its functional separation from additional assumptions. As we move toward more complex, multiprocessor, architectures based upon distributed underlying processing capabilities, these problems become even more severe. The two proposals listed below reflect similar concerns to those of Fox et al., but are pursued by different means. The objective in both cases is to provide means of making theory explicit in an abstract but unambiguous form, while enabling it to be scoped appropriately to generate predictions in specific circumstances.

B1. Rule-Based Approximate Modelling: The kind of rule-based modelling (section C of past work above), is based upon a theoretically driven approximation of the functioning of the ICS multiprocessor architecture. Although not a simulation, the required theory is abstracted into explicit rules for reasoning about cognitive activity. It is also appropriately scoped in that the rules are also explicitly laid out (a) for establishing task and other external conditions and (b) for the conditions in the approximations for which particular predictions about behaviour apply. The UK product in which our past work was implemented has recently been discontinued. In this context and that of the alteration of Barnard's research interests, it is proposed to start a complete reimplementation of the theoretical modelling rules in a new environment, but this time, scoped for the prediction of the results of laboratory experiments. Initially, it is proposed to concentrate on those issues in the deployment of visual attention and multimodal blending that are described below. This particular proposal requires the full time support of a post-doc and is heavily dependent upon having access to skills in both AI and ICS. Jon May has both set of skills. Accordingly funds will be sought to support his further involvement. Failing that, and with great reluctance, this particular proposal will be dropped.

B2. Formal Methods and Human Cognition: In section D above, it was noted that a group of computer scientists have become interested in the formal specification of the conjoint behaviour of users and computer systems. They use the same form of logic to represent abstract properties of both a computer interface and the human interacting with it, and then seek to model the behaviour of a complete "system" composed of these constituent agents. Armed with an appropriate schema for the discharge of a proof, this could form a basis for formal theory-based reasoning about cognition. In this context, it is interesting to note that the approach has two really interesting features. First, it is an appropriate level of abstraction for representing "core theoretical claims", yet is technically capable of refinement into increasingly detailed claims. Second, the approach has a built in means of scoping the theoretical claims about cognition. In order to model the interaction, it is necessary to model the salient features of both parties. In this case the system model and the interaction must represent the relevant aspects of the environment in which cognition is occurring and the tasks it supports. In technical sentiment, this could not be further removed from Suchman's (1987) approach to situated cognition. Nonetheless, broadly similar issues and problems may be addressed precisely.

At present, it is unclear whether formal proofs can meaningfully be discharged in this context. By the end of the AMODEUS project, sufficient specification work will have been done for ICS and system models to exist for a number of very specific cases in multimedia communication and air traffic control. We propose to use this material as a basis for exploring the issues raised in greater detail.

C. Empirical Proposals *(Barnard, Scott)*

C1. Central Functions and the Dynamic Processing of Complex Visual Scenes: Our general approach (work completed, section B) assumes that the dynamic deployment of visual attention can usefully be analysed by considering how the most central processes within the ICS framework control thematic transitions in structural descriptions of visual scenes and the objects they contain. The deployment of attention is related to the number of objects in a scene sharing a common psychological subject description and the depth to which predicate evaluation must proceed to ensure target discrimination (2.52). Depth is not, however, a unitary dimension. The same number of items, with the same degree of depth, can be embedded within markedly different constituent organisations (e.g. object grouping). We propose to extend our recent experiments on icon search by testing the hypothesis that intermediate structures must be processed in attentional transitions which cross levels (up or down) in the structural description of visual scenes. This will be accomplished by systematically manipulating (a) the way in which constituents at various levels are grouped together and (b) the relationship of the target's description to those of the surrounding constituents.

Classical searches for targets in arrays represent only one form of attentional transition. In computer displays, theatre and film, the change of scene or objects within a scene can be either continuous (panning; scrolling of information in a computer window) or discrete (cuts; opening new window environments). When discrete changes are made, only some seem to support thematic continuity in scene processing. Using alternative "film cuts" in short computer controlled animations (c.f. Frith & Robson, 1975; 2.173), we propose to investigate how thematic continuity is maintained by systematic substitutions of individual subject and predicate components presented within the current visual field.

C2. Cross Modal Integration of Information: Work on thematic continuity in the processing visual scenes provides one way of examining how central mechanisms interact with incoming streams of information. Information from different modalities (or sources) is systematically correlated in well known ways. Lip movements are correlated with voice sounds and such correlations can lead to well known blending effects with cue conflict (e.g. McGurk & MacDonald, 1976) or specific attentional effects in infants (Bahrick, 1988). Similarly, expressed meaning may be systematically related to concurrent facial expression, tone of voice or physical gestures. Within the ICS framework the possibilities for information flow among subsystems are clearly defined and constrained such that different forms of information blend at different levels within the subsystem organisation. Tone of voice and facial expression are integrated at the level of schematic rather than propositional meaning (Teasdale & Barnard, 1993) whereas information derived from lip movement and speech blend at the level of structural descriptions of speech form. Concurrent verbal and deictic reference will be resolved at the level of propositional meaning and so on.

It is hypothesised that the blending of information derived from different modalities or sources is determined by the properties, and the arrival timing, of the current psychological subject at any level of encoding within the ICS architecture. If these move outside limits determined by the particular mental code involved, then thematic coherence cannot be established and two data streams will be established. According to the model, only one stream at a time can then be selected for further processing. A well known instance is when a soundtrack goes slightly out of synchrony with a film. Like the concept of perceptual centres, cross-modal synchrony must rest on internal attributes of the data streams, rather than everything starting and stopping at the same time. If perceptual centres can be found in any data stream and if cross modal information is to be attributed to the same source or event, these different perceptual centres must be aligned, or synchronous. Initially, we propose to investigate cross modal blending by studying the internal properties of verbal and visual data streams, manipulating relevant properties of form and timing within computer controlled displays. Video-recordings of real faces and more coarse grained animations of faces should be subject to different influences. The high quality images of faces should provide conditions for phonological cue conflict. Coarse representations in animated facial characters should be associated with higher level attributional blending at a propositional level of representation. The relevant psychological subject and predicate structures at these levels should differ and thus the acceptability of thematic transitions should be influenced by different parameters.

C3. Unpacking Cognitive Control Aspects of Central Executive Functions (collaboration proposed with Fowler at the Department of Psychology Fulbourn Hospital): The previous two experimental topics both focused upon rather different relationships between central processing activity and incoming data streams. As a part of a recent theoretical exercise, Barnard (1994) has developed a set of inter-related proposals concerning the analysis of central executive functioning within Interacting Cognitive Subsystems. Central executive functions are implemented in terms of processing exchanges between propositional and schematic levels of meaning. One part of the analysis addresses the issue of what might happen if the temporal synchrony of the exchanges between propositional and schematic levels were to break down. It is hypothesised that a breakdown in the synchrony of exchanges between propositional and schematic levels would lead directly to a separation of information that should be correlated within the same data steam. In an analogous way to the separation of lip movements and soundtrack, the individual would be "aware" of two distinct data streams. Only one would be predicated to the sense of self - and the other could potentially come to form the basis of some delusional system about alternative sources of agency to which "voices in the head" may become attributed.

These particular proposals about asynchrony within central executive functioning bear some similarities to Frith's (1992) information processing approach to understanding schizophrenia. Fowler & Barnard intend to explore the asynchrony hypothesis by monitoring a population of schizophrenics over time. Although delusional systems may become stable and assume a chronic schematic pattern, the asynchrony should be most marked when a patient is "in episode" compared to periods when "not in episode". It is proposed to monitor their performance on specific tests requiring schematic evaluation - such as Shallice's cognitive estimates test, and tasks involving the generation of random numbers within defined instructional constraint. Pilot work on this latter tasks indicates that slips comparable to failure on cognitive estimates occur at a significant rate - even in the normal population. It is also proposed to use the case grammar techniques, outlined in the cognition and emotion programme, to study schematic properties of self and agency within this particular population and to assess whether or not such properties shift systematically as patients move in and out of episode.

COMPLEX COGNITION IN LEARNING AND USING INTERACTIVE DEVICES *(Blandford, Howes, Whittington, Young)*

Introduction

This area of research is aimed at understanding, through modelling, cognition in tasks more complex than those typically studied by laboratory investigations in Cognitive Psychology. The central underlying theme is that detailed computational theories and models have much to offer in helping to illuminate human cognition, but that, in order to be helpful, those theories and models have to be developed in ways sensitive to both the psychological and the computational constraints.

Most of our research has exploited the existence of the cognitive architecture called Soar. Soar is a problem-solving architecture constructed as a nested set of problem spaces. Problem solving consists of the repeated application of an operator to a state in a problem space to yield a new state. When an impasse occurs which blocks this process from continuing, Soar automatically sets up a subgoal with its own problem space, the purpose of which is to resolve the impasse and allow processing to resume in the original space. Closely associated with this goal-subgoal structure is a mechanism for learning by chunking, which stores the results of processing in a subgoal as new rules, so that in future occurrences of a similar situation, the rules will apply and the impasse will be avoided. Soar has its origins among attempts in Cognitive Science to build what are now being referred to as "Integrated Intelligent Architectures", information-processing organisations which combine two or more of the basic components of AI, such as planning, knowledge representation, vision, etc. In his 1990 book on Unified Theories of Cognition, Newell lays out the Soar account of cognition, and makes the case for theories which integrate diverse findings from different areas of psychology into a coherent whole, and for Soar as a candidate for such a theory. Soar is useful in our investigation of cognition because, among other reasons:

• Soar's emphasis on unification provides a good basis on which to build models that integrate different aspects of cognition in the performance of a complex task, as is explained below.

• The close intertwining of learning and problem solving in Soar makes it feasible to include learning within the phenomena covered by models of cognitive skills, in a way that until recently was not possible.

• Soar's being a strongly constrained architecture provides some much-needed help in alleviating the problem of "theoretical degrees of freedom". Instead of, as in other approaches, having the theoretician simply posit a model for a task, with Soar it becomes more a matter of discovering how Soar would do the task. This is what Newell calls "listening to the architecture".

Soar investigators constitute a distributed research community located at a dozen or so sites in the USA and Europe. The existence and responsiveness of that community (e.g. to technical queries or scientific debate conducted over email) has been of great help to our research. In 1992/93 Young and Howes spent an academic year at Carnegie Mellon University, Pittsburgh, Pennsylvania, working at one of the principal Soar sites. We have contributed to making the case for Soar as a theory of cognition (2.119), and to debate about its theoretical status. In collaboration with Frank Ritter of Nottingham University, Young has been developing a tutorial introduction to cognitive modelling in Soar, which has now been presented several times in both half-day and full-day versions.

A. Towards an Integrated Model of Learning and Performance *(Young, Howes)*

Much of our research has been done as part of two consecutive projects funded by the Joint Councils Initiative in Cognitive Science and Human-Computer Interaction. The aim of the projects has been to develop models of users of interactive devices within an appropriate cognitive architecture, in a way that both advances the art of user modelling and also contributes to a fundamental understanding of the cognition involved in performing realistically complex tasks. The second project is still continuing, while the first was assessed after the final report as being very good (with one of the three external referees awarding it an outstanding).

Our work on the first project began from the observation that even experts' skill at using an interactive device, such as an Apple Macintosh personal computer, is display-based and situated: It is evoked in the context of use, and utilises information from the display, but is not necessarily accessible to the user away from the device. Drawing on a prior analysis (Howes & Payne, 1990a) which extends the formalism of "task-action grammars" to handle aspects of display-based skill, we examined what would be required for a Soar model to acquire the task-action mapping rules for a display-based task. The result was the Task-Action Learner model (TAL). "Task-action mapping" refers to the sequence of physical actions (moving the mouse, clicking a button, …) required to carry out a unit task on the device. The model simulates a person learning to use an interface by trying to perform tasks, guided where necessary by advice from an external tutor, and reveals how the mappings from simple tasks to actions are dependent upon the detailed dynamics of the device's display (2.40, 2.75; Howes, 1992). It exhibits at least four empirically observed phenomena of HCI:

• It learns consistent interfaces more easily than inconsistent ones. For example, it needs to consult the tutor less often in cases where the methods for using the device are consistent with the model's semantic categories.

• It speeds up with practice, in part by learning the location of particular items on the display.

• It is sensitive to the actions afforded by the device display, so that highly interactive devices are easier to learn.

• It remains dependent upon the display to cue its memory for methods, as do even very skilled users.

The TAL model exhibits at least two kinds of interactivity: (1) The repertoire of low-level actions it considers at each step is determined by the affordances offered by the device display. (2) It relies upon information presented by the device to flesh out the details of an action, which can therefore be represented in a general semantic form to be instantiated appropriately in a range of different task situations. This work on learning task-actions mappings extends our earlier research on Programmable User Models in HCI by having the analyst instruct the model rather than program it, and by assessing the learnability of an interface rather than its plain usability.

Because it depends on advice, TAL performs guided learning, while people often engage in genuinely exploratory learning. To understand this ability, we again drew on some of our earlier work (2.54, 2.55; Howes & Payne, 1990b; 1990c) and extended it to a new model (2.144). It is becoming clear that recognition knowledge (as against, e.g., recall knowledge) can by itself make a major contribution to guiding the user during exploration of an unfamiliar interface. Such knowledge is easier to acquire, and is "cheap" in the sense that it is needed anyway to support the learning of the more complex knowledge required for control or recall. The model of exploratory learning uses heuristics based on recognition knowledge together with control knowledge which is learned as it becomes available. The model (2.39) exhibits behaviour known as final-first learning, with these characteristics:

• It learns by exploration through interacting with the device.

• It learns the later parts of the sequence first.

• It speeds up with practice.

• It acquires display-based (or "situated") knowledge.

The latter two characteristics are shared with TAL, though the speed-ups occur for different reasons. TAL becomes faster with practice because it avoids the task decomposition and automatises the control decisions that it initially makes deliberately. The exploratory model performs the task faster because it learns the menu structure.

Stepping back from the individual models, we have also made a preliminary attempt to articulate the space of models used in modelling cognition within Human-Computer Interaction. The work is a precursor to the development of an integrated model (see below, under Future Work) (2.114, 2.115). The intention is to provide a theoretically motivated and conceptually consistent overview of the literature on cognitive modelling.

B. Approximate Modelling of Cognition and its Application *(Young, Blandford, Whittington)*

Some of our work has been done as part of the AMODEUS project, a large, multidisciplinary, European collaborative project which has been co-ordinated by P J Barnard and is described more fully in his section of this Progress Report.

B1. Programmable User Models: Within the context of the Amodeus project, our approach builds on the earlier idea of "Programmable User Models" (PUMs) developed under an Alvey project. This approach postulates that designers can gain insight into the problems of usability by attempting to instruct an architecture with human-like constraints how to perform tasks with a device corresponding to the design they have developed or plan to implement. Initially we focussed on the planning component of the PUM, developing a scheme for making means-ends analysis available ubiquitously in Soar (2.178). When applied to a simple HCI situation, this yielded predictions of a class of conceptual errors (2.68), and also generated a small space of possible behaviours. Some of these behaviours do the task "correctly", i.e. as intended by the interface designer, some achieve the task but do so inefficiently, and some lead to irrecoverable error.

We analysed the knowledge needed by users to perform a given task with a proposed device — such as opening a document within an application running on an Apple Macintosh personal computer (2.67) — and how that knowledge can be expressed in an Instruction Language and compiled into rules for the Soar architecture (2.5). Starting from what the designer intends as the correct sequence to accomplish the task, we analyse what knowledge the user needs in order to know to do each step at the right time, and to know how to do the step. This knowledge is then expressed in the Instruction Language, compiled into rules, and run as a cognitive model. As the model runs, it acquires new rules which proceduralise the performance of the task. That procedure, reconstructed through this cycle of analysis and synthesis, may or may not correspond to what the designer originally specified, and in either case can be revealing of issues concerning the usability of the proposed design.

B2. Analysis of Concrete Scenarios: As noted in Barnard's contribution to this programme of the Progress Report, we have continued to develop a method for assessing cognitive (and other) modelling techniques by applying them to concrete behavioural and design scenarios. In addition to the methodological aspects (2.66, 2.122), we have shown how our approach explains a persistent error committed by people who use multi-window computer screens, in which they type input intended for one window whilst another window is still active (2.64).

B3. Design Rationale: In collaboration with partners at Rank Xerox Cambridge EuroPARC, Young has worked on the development of an analysis and associated notation for representing design rationale. Normally when some object or device is designed, all that is left at the end is a blueprint or the artifact itself. All the reasoning, argumentation, exploration, and justification that went into its design gets lost. The lack of that information makes subsequent processes of maintenance, modification, re-design, and explanation much harder and less efficient, and makes it difficult to re-use parts of the design for other purposes. Our technique, known as design space analysis, attempts to redress those defects, and aims to represent why a design is the way it is

(2.46, 2.48). The notation centres on the use of Design Questions, Options, and Criteria, and provides an explicit representation for part of the design space surrounding the artifact. Considerations of usability, and more general psychological aspects, enter mainly as criteria, or as justifications supporting the assessment of design options against criteria. Our approach has been influential within the general growth of interest in design rationale. It is used for various purposes within Amodeus (2.146), for example to analyse the role of analogy and metaphor within interface design (2.47).

C. Devices and Agents

Some work on people's understanding of complex devices draws its inspiration from Young's research in the early 1980s on users' mental models of pocket calculators. (See also 2.56) Elizabeth Churchill, the holder of an MRC Collaborative Research Studentship with Rank Xerox EuroPARC, showed both by modelling (2.126) and empirically (2.160) how different instructions to calculator users, even where these lead to the same overt performance on the training material, yield different internal representations of the skill which generate observable differences on diverse tasks. She also showed that in using such devices, people form only shallow, local plans which specify in detail only the immediate next steps, with the direction of future steps sketched only loosely and left to be determined, opportunistically and interactively, by the behaviour of the device. Working with another (non-APU) graduate student, John Bradshaw, we showed how adding an explicit depiction of purpose to the kinds of representations used in Artificial Intelligence and Knowledge Engineering for dealing with complex devices, enables us to facilitate reasoning about the device for the purposes of design, or diagnosing faults (Bradshaw & Young, in press). Typical applications of Bradshaw's work are to the understanding of central heating systems (2.6) or the triply-redundant hydraulic system of the BAe 146 aircraft (2.60).

Since joining the APU, Blandford has maintained an involvement with research on agent architectures for interaction and collaboration, drawing on her PhD thesis work on the design and implementation of an Intelligent Educational System to support the teaching of decision making in design (2.4). The focus of this work is on the architecture of the agent, and the knowledge it needs to enable it to engage in a mixed-initiative dialogue with a user and solve problems collaboratively (through a process of negotiation) (Blandford, in press, a). As well as being equipped to deal with knowledge in a non-prescriptive way, the agent takes account of motivational factors in deciding what to say to the user. The agent architecture is based on an 'action cycle' which governs changes to the internal state of the agent, causing it to acquire goals and become committed to actions on the basis of its beliefs about the current context (Blandford, 1993a). The relevant aspects of context include mutual commitments (what the system and user have agreed to do together), open topics of conversation and the agent's current beliefs (including those about the user's beliefs). The agent is largely opportunistic, and does not engage in advance planning. In deciding what to say or do to satisfy its current goals, it selects the action which it believes will best satisfy its values while also contributing to satisfying its (achievable) goals. In the current implementation, actions include deciding what to say or do, saying something, doing something (generally updating information in a spreadsheet which supports the problem solving) and receiving and understanding input from the user. Values include, for example, keeping the interaction varied and purposeful, encouraging the user to reflect on their beliefs, and doing the minimum

(Blandford, in press, b); this agent (implicitly) derives pleasure from having the user learn well and expending the minimum of effort! Results of an informal evaluation of the current implementation are encouraging (Blandford, 1993b). Future work will include developing fuller knowledge structures to support richer interactions and testing the same basic architecture in different domains.

FUTURE PROPOSALS

Our future work falls into two parts, both of which are concerned with various kinds of integration.

A. Integrating Different Aspects of Cognition

Current theories in cognitive psychology offer only fragmented accounts of human learning and performance in a real-life domain such as Human-Computer Interaction (HCI). Models derived directly from the results of experimental psychology focus primarily on just a single aspect of cognition (e.g. perception, motor control, planning, or problem solving). But because many everyday activities — such as those involved in using a technological device, for example withdrawing money from a bank cash machine, or discovering how to use an unfamiliar software application on a familiar computer like an Apple Macintosh — draw on many aspects of cognition at the same time, such fragmentary models are either too narrow and fail to predict important phenomena, or else are too loosely scoped and make incorrect predictions through being applied outside their proper domain. One of the advantages of carrying out research on Cognitive Science in an applied area such as HCI is the opportunity it provides to redress this shortcoming, by turning the problem around, focussing on the application, and drawing in the cognitive capabilities needed for handling the domain. The challenge is to offer an integrated account of learning and performance in such a task. There are major theoretical and technical difficulties to be overcome in providing such an account, but the way has been pointed (and inspiration provided) by the initial proposals for "integrated cognitive architectures" such as Soar, and Anderson's ACT-R. Our own research with Soar over the past few years — for example on planning in the context of HCI, and on exploratory learning — has made enough progress to confirm its potential, but most of the work remains to be done.

A1. Modelling Cognitive Capabilities: Our approach, being pursued in the second round of funding from the Joint Councils Initiative, and to be continued beyond, has two parts. First, we focus on the provision of various generalised cognitive capabilities. For several of them, we already have some understanding of how the capability can be modelled. Examples are:

• Mini-planning, by which we mean a limited capability to perform simple problem-solving and planning. As already mentioned, the planner makes general use of means-ends analysis.

• Interactivity, here meaning the user's exploitation of, and reliance upon, information and affordances offered by the device, and therefore shared by the user and the system. We have already explained how the TAL model exhibits at least two kinds of interactivity.

• Acquiring task-action mappings. As already described, TAL models the learning of task-action mappings, and their generalisation over semantic categories of the task.

• Rapid initial learning refers to the dramatic speed-up with practice observed over the first few trials on a task. The speed-up has been demonstrated most clearly in the case of TAL, but it occurs equally with means-ends analysis, and indeed is ubiquitous in Soar-based models.

• Exploratory learning has been described at length above.For the kind of integrated model we are aiming at, further capabilities are needed. Examples are:

• Goal representation. The present models have no representation of what they are trying to accomplish when performing a task. They have an encoding of the task, but no notion of what that means in the domain. Giving a model a representation of what it is trying to accomplish will overcome two of the limitations of TAL. First, the model will be able to recognise when it has reached a goal or subgoal. (At present, TAL has to be told explicitly when it has finished each level of a task.) Second, the model will be in a position to assess the correctness and quality of the advice or guidance it receives.

• Variety of knowledge sources. An integrated model needs to be able to utilise a range of different kinds of knowledge: lexical knowledge, semantic knowledge, display knowledge, locational knowledge, knowledge of methods, domain knowledge, and so on.

• Visually-driven processing. Much of the use of interactive devices is driven strongly by the information presented on the display. Existing Soar models do not reflect this dependence at all well. TAL, for instance, employs a notion of visual frames, but although helpful, this is inadequate for capturing typical cases of visual layout. We are encouraged by how far our colleagues Barnard and May have been able to go with the (non-Soar) modelling of visually-guided behaviour by employing a plain hierarchical representation of visual structure combined with simple rules for processing that structure (e.g. 2.51). We will, of course, not attempt to model the low- and medium-levels of visual perception that parse the raw image into a structured visual description. Our interest is not in that process of parsing, but in the interpretation and use of the resulting parse. The requirement is for a model to be able to combine knowledge of the task with a description of the visual layout in order to guide its further problem-solving and behaviour.

A2. Combining Capabilities: Second, for the integration itself, the main challenge is posed by the observation that models implemented independently, even in Soar, inevitably make certain assumptions or pre-empt certain decisions in ways that make it difficult to combine one capability with another. So the methodology of this part of the research takes the form of an iterative cycle in which we repeatedly:

(a) Analyse existing approaches (our own and others') for providing the relevant cognitive capabilities, in order to uncover the core of each approach.

(b) Discover a means to realise each capability in a way that respects and exploits the Soar cognitive architecture, whilst remaining compatible with the other capabilities as well as with a broad range of empirical properties of cognition.

Several of our existing models provide illustrations of early steps towards integration, especially in that they combine learning and performance. Howes' model of exploratory learning, cited earlier (2.39), is one example, where the final performance, of being able to perform a set of tasks fluently, depends upon learning the hierarchical menu structure. Another is an initial investigation into modelling the use of deliberate analogy in performing and learning a new task. With colleagues at the University of Colorado at Boulder, we constructed models in Soar and in Anderson's ACT-R for a simple analogy task, that of inferring how to start a new program on an Apple Macintosh given that the user already knows how to start some other program (2.57). (The comparison between the two architectures was instructive.) The more interesting properties of the final performance Soar model — such as that there is positive transfer to subsequent instances of analogy, even though the mapping rule learned in each case is specific to the given task — depend crucially upon the process by which it was learned.

Within a couple of years, we expect to be able to model the performance of a user who draws on a variety of sources of knowledge and deploys a range of tactics in order to learn to cope with an unfamiliar software application. The model would explore and learn relevant parts of the command structure of the application, use simple lexical knowledge in relation to the semantics of the task it is trying to perform, apply knowledge it has of other related applications in order to make "informed guesses", and when necessary simply try things out to see what happens. Starting from this initial stage of uncertainty and trial-and-error, the model will with experience become "expert" at a range of tasks performed with the new application, and will be in a position to use its newly acquired knowledge of the application to support the learning of yet others.

A3. Accounting for Detailed Data: Having such a model will put us in a position to relate the models to empirical data in a different way than we have done so far. At present, the models are constrained by data in the form of empirically supported regularities, such as those mentioned earlier: that people learn consistent interfaces faster than inconsistent ones, that they speed up with practice, that even experts remain dependent upon the display, and so on. The integrated model will make it possible to perform comparisons with more detailed data, such as studies of individual learning trajectories and experiments chosen to probe particular aspects of the account.

A4. Implications for Basic Cognition: Because of its integrational nature, the modelling based on the Soar cognitive architecture often has implications for basic 'laboratory' phenomena of lasting concern in cognitive psychology, many of which seem to cry out for detailed modelling: resource-limited cognition (which is dealt with at length elsewhere in this Report, e.g. by Barnard); implicit and explicit learning; dual-task performance (again, dealt with in detail elsewhere, e.g. by Duncan); and so on. Soar offers a distinctive theoretical perspective on such phenomena, and when successful, that kind of modelling yields both an integrational account of the phenomenon in question and also serves to modify and further specify Soar as a psychological architecture. For example, to the currently confused distinction between 'implicit' and 'explicit' cognition (which is rapidly threatening to become one of those diffuse ideas in psychology which mean something different to each investigator), Soar brings to bear two relevant contrasts: (1) All permanent knowledge is encoded as content-sensitive pattern rules in LTM, and is not directly accessible to awareness, whereas dynamic information about the situation being dealt with is encoded as data in working memory (WM) and is available to awareness (though it may or may not be verbalisable, depending upon the nature of its content); (2) Rules which work directly to modify the current state correspond to automatic processing, and are not under the voluntary control of the person, whereas rules which modify the state via the current operator correspond to deliberate processing, and are under the person's control. The cognitive activity in the performance of any actual task results from the interaction among these different sources and ways of deploying knowledge.

Consider what happens in a task where the correct action depends upon making distinctions not initially known to the subject — as is the case in experiments requiring the control of complex systems, the learning of artificial grammars, and so on. One possibility is for the subject more-or-less passively to let the experience of different cases accumulate. The kind of performance that will result will depend greatly on the precise circumstances of the task, but in any case the resulting ability will take the form of non-articulated skill, distributed across the rules in LTM — one clear sense of "implicit" knowledge. Alternatively, the subject may be able to pursue a more active problem-solving approach, forming and testing hypotheses, and asking herself questions about the relevant features on which the discrimination depends. As a consequence, she may be able to formulate an explicit regularity ("after two UPs I have to go DOWN") which is held in WM and comes to play a role in determining her behavior — a clear case of "explicit" knowledge. The possibilities, and the interplay between the different representations of information and with the learning that results from them, all depend on the precise details of the experimental task and the subject's strategies in a way that requires detailed cognitive modelling to tease apart.

In the longer term, the integrational approach can sometimes suggest new accounts for old phenomena. One such possibility concerns the nature of limited working memory (WM). Although the limitations of WM are usually interpreted as reflecting a limited resource, it is possible to find a functional explanation for many of the phenomena, and one can argue on general grounds that where both accounts are available, the functional account is preferable (2.121). Functional explanations include, for example, arguments that any system with the known capabilities of humans will exhibit the phenomenon in question, or that the phenomenon arises from a design trade-off such that humans are better off with the "limitation" than without. Another functional explanation is to show that only a limited amount of WM is needed for a task. In Howes' model of exploratory learning (2.39), for example, because the learning is guided by knowledge acquired and stored in long term memory, only a bounded amount of working memory is required independent of the size and shape of, e.g., the menu structure to be learned. Most existing search techniques, in contrast, require a goal stack that grows with the size of the space to be searched. Over the next few years, it will be interesting to see how far this general line of argument can be carried.

B. Integrating across Disciplines

Another issue is integrational, though this time in a different sense: across disciplines, rather than just across psychological areas. A major opportunity and challenge arises from the collaborative projects in HCI we have been engaged in during the past few years. As a result of the Amodeus projects, we are just beginning to understand the relationships between different kinds of modelling derived from different disciplines: formal system analysis done by computer scientists, cognitive analysis by psychologists, design space analysis, and so on. The question then arises of how to combine them, in order to paint a more complete picture of what happens in HCI, whether for practical reasons (giving guidance to interface designers) or theoretical (understanding the nature of human-computer interaction). The work poses difficult conceptual puzzles, such as how to reconcile the view of the user implicitly assumed in most HCI work in computer science with the view proposed by more psychological work on user modelling. There are also considerable technical obstacles, such as trying to understand and interrelate the different languages used by the different disciplines (mathematics, logic, cognitive task analysis, design rationale, …). The potential reward, though, is a deep, cross-disciplinary understanding of cognition in tasks requiring interaction with a complex device, that respects both the psychology of the person and the nature of the device.

B1. Multi-Disciplinary Modelling: One of several ideas within Amodeus about how such an integration might go is sketched in a recent paper which discusses the multi-disciplinary analysis of an "Undo" function for a collaborative computer application (2.65). The paper summarises six different modelling analyses of the same issue from different perspectives, two being psychological, two having to do with system modelling, one focussing on design, and one directly on the interaction between user and machine. It then proceeds to build an account of how the different threads can be woven together to tell a story that is richer and provides more insight into the user (and system) issues than can be provided by any one perspective alone. Current and future research is aimed at extending this work, to discover if there are other and perhaps better ways to fit the pieces together.

B2. Formal Modelling: At the present moment, a somewhat more formal method, using descriptions based on algebra and modal logic, looks promising for integrating at least the psychological and system models. The idea is that the behaviour of relevant aspects of the computer system be described by means of logical expressions that specify the transitions between system states. On the user side, the effects of possible user actions would be similarly described. In many cases the user's knowledge of the system state is indirect, in other words the user knows that the computer holds certain information, but does not herself know what that information is. For example, in the case of an address book held on the computer, the user knows that the computer has names and addresses, but does not know the actual addresses. Because of this indirectness, the user's knowledge has to be represented by a modal rather than a classical logic. The appropriate kind seems to be an epistemic logic, because the information to be represented is analogous to that involving beliefs about other people's knowledge (as when representing situations such as that Fred knows that George knows Susan's birthday, but does not know it himself). It then becomes feasible to deduce, for example, that the user can know that if she follows a certain strategy she will succeed in getting certain information (such as Murgatroyd's address) from the computer. Such deductions are more powerful than the simulations (of user and of device) that we are performing at present. Indeed, simulation interestingly enough turns out to be a restricted case of deduction. It emerges when the deduction takes a particular form, namely an alternation between inferences based just on the system representation and inferences based just on the user representation. This work is closely related to the approach proposed by Barnard in his Section B, Formal methods and human cognition.

C. Devices and Agents

No future work on these topics is planned.

STUDY AND MODELLING OF TRANSPORT SYSTEM USERS (Brown, Chapman, Groeger)

Introduction

The importance of psychological research on driving: The driving task is of immense social importance (see 2.11, 2.87). Recent figures indicate that the vast majority of the adult British population hold driving licences (e.g. 90% of all males and 50% of all females between 30 and 60 years of age). The female driving population is also growing rapidly. Meeting this continuing demand for independent mobility poses both economic and theoretical challenges. Maintaining and extending the road network is a substantial fiscal pressure on any economy. Further growth in the motoring population almost inevitably leads to a growth in congestion, a reduction in the cost effectiveness of road transport and a consequent increased demand for further extensions to the road network (2.7, 2.87).

Casualties also have economic consequences. In 1989, over 5,200 people died on British roads. It is estimated that about 70,000 suffered serious injuries, about 400,000 suffered slight injury accidents, and in the region of 2,000,000 damage-only accidents occurred that year. The personal cost of road traffic accidents, in terms of the psychological stress and trauma caused to the survivors, remains unquantified, but must be substantial. The economic costs are rather more clear: for 1989 the cost of these accidents was estimated to be 7.4 billion pounds. Although the fatality figures to be released in 1994 are likely to reduce to somewhere in the region of 4,400, the comparatively stable incidence of injury, increased actual cost of accidents and larger numbers of younger and older (i.e. higher risk) drivers in the population all suggest that road traffic accidents will continue to constitute a substantial social and economic problem, whether or not Government targeted reductions in casualty rates are achieved by the year 2000 (see 2.86).

Another aspect of the driving task which is worthy of note is the role of developments in vehicle and road technologies. Recent pan-European research initiatives such as DRIVE and PROMETHEUS have attempted to bring together industrial research and development teams, academic researchers and traffic engineers in order to develop intelligent vehicle and road applications for the transport system of the last years of this century and beyond. Such applications are intended to improve safety, efficiency and congestion by reducing the scope for driver error (2.53). The importance of behavioural considerations in the development and evaluation of such applications cannot be overstated, nor can the potential for wealth creation and employment opportunities afforded by the equipping of hundreds of millions of vehicles with new technologies (2.53, 2.128, 2.175).

Contributing to these societal goals of safety, efficiency and wealth creation, whilst also building and extending the theoretical basis of psychological research on driver behaviour, have been the aims of the Unit's long-term programme of research in this area. The work had its origins in studies conducted by Bartlett and his colleagues during World War Two. The continuous programme of research that followed this initial work may be divided into three broad areas of enquiry: the acquisition of skills, the effects on performance of task-induced and environmental stress, and problems arising at the interface between transport technology and its operators. Throughout this programme, the emphasis has been on attentional, perceptual and cognitive skills, rather than on lower-order vehicle control skills, although the latter have necessarily been included as important dependent variables in many studies, particularly those concerned with the development of methodology. In the current period, the work included a range of attempts to investigate different aspects of drivers' learning, drivers' appreciation of risk and decision making, the role of memory in drivers' assessments of danger and error, and drivers' self-assessments of skill. These theoretically driven research interests have benefited from substantial external funding, to the tune of around half a million pounds, in the period of this report.

A. Investigations of Drivers' Learning

Despite the fact that in the region of 95% of those learning to drive take at least some formal training before their driving test, and the fact that drivers with different levels of traffic experience are differentially involved in accidents, there have been few systematic studies of drivers' learning (for discussion see 2.100, 2.131, 2.134). Two approaches have been adopted in our research, one which seeks to examine the whole range of what it is drivers are required to learn, and one which seeks to examine the effects of instruction under controlled conditions (see 2.101, 2.170 for discussion of how the two interact).

A1. Learning During Training: The series of investigations involved the video recording of each and every driving lesson taken by 20 teenagers learning to drive for the first time. The content of these video tapes was analysed, and each manoeuvre, statement by the instructor and error by the pupil was recorded. Unusually in a British context, these drivers did not drive between lessons, and thus the Driving Instruction Database provides a unique record of the early learning experiences of these novice drivers. The collection, coding and initial analysis of these data was carried out as part of our efforts within the CEC funded Generic Intelligent Driver Support project by Groeger and Grande (2.109, 2.139).

The analysis of the database has been continued by Groeger and Clegg, with funding from the Department of Transport. A variety of results have emerged from these analyses, a few of which are particularly worthy of note. Drivers undertake in the region of 2,000 manoeuvres when learning to drive. Almost all of these are commented upon by the driving instructor at the outset, while at the end of the course the rate of instruction per manoeuvre is much reduced, but only for certain manoeuvres. From other analyses it would seem as if the withdrawal of instruction (or "instructor independence") is well described by a power law for each pupil studied. This raises an important issue, as yet unresolved, about the nature of practice in complex tasks such as driving, and where it is most appropriately placed on the traditional "massed-distributed" continuum (see 2.100, 2.134, 2.135). These analyses also make clear that certain manoeuvres are performed relatively infrequently and rather erratically during the course of lessons, with the result that they appear to be learned less rapidly. This is especially the case for manoeuvres which require decisions to be made about the possible actions of other road users, and those which require some assessment of danger. The comparative infrequency of such manoeuvres, and their more or less random dispersion across lessons, raises the possibility that higher-order decision making skills cannot be adequately acquired by drivers during traditional courses of driving lessons. This prediction carries with it the implication that vehicle control skills, which are frequently performed in a wide variety of contexts, will be quickly acquired and relatively enduring.

A2. Learning under Controlled Conditions: Research carried out as part of our efforts within the CEC funded ARIADNE project by Groeger and Kuiken (University of Groningen), using the fixed-based interactive driving simulator at Groningen, has investigated drivers' learning under more controlled circumstances. A series of studies revealed that in the absence of augmented feedback drivers performed consistently, but inaccurately, in the simulator (2.167). Where instruction was made contingent on the occurrence of errors of various types, the rate of those errors referred to in the instruction decreased. Improvements were not observed where the support given was not contingent on performance (2.145). More interesting from a theoretical point of view was the fact that, while drivers were aware that their performance had improved in the supported scenarios, they were unaware that their performance in other scenarios had also altered. By careful manipulation of elements of the scenarios used, it was clear that such transfer occurred only for those scenarios which were functionally similar (i.e. support on curves altered performance on curves and roundabouts but not at intersections; whereas subjects reported that their performance changed on curves, but not on roundabouts or crossroads). As another example of "implicit" learning, behaviour changes at green traffic signals carried over to junctions where the driver had right of way, but not to junctions where the driver did not have right of way (see 2.111, 2.141, 2.168).

The results from these two lines of work have clear practical applications, with respect to the redesign of driver training curricula and to the development of effective in-car performance support devices (see 2.102, 2.106, 2.138). They also serve to echo, if not extend, current theoretical debates in human learning (2.105).

B. Drivers' Decision Making and Appreciation of Risk

B1. Decision Making on the Approach to Traffic Signals: Our investigations of drivers' decision making on the approach to signal-controlled junctions was initially motivated by practical rather than theoretical concerns. As part of their efforts to understand why 40% of all accidents take place at urban intersections, the Department of Transport funded a joint research project between the APU and a traffic engineering group at University College London. Laboratory-based empirical work by Groeger, Grande and Brown made extensive use of a "time-to-coincidence" task. This revealed that drivers consistently underestimated how long it would take to reach a set of traffic lights towards which they were travelling (2.137, 2.140). Estimated and actual arrival times were related by a power law. Work built upon this paradigm revealed that drivers were confident when taking "stop" or "go" decisions when confronted with amber onset, even though their estimates of when the junction were reached would have been highly inaccurate (2.149, 2.166). Furthermore, the studies strongly suggested that these two decisions were typically made at different points on the approach, rather than at the same stage. Recent reanalysis of these data suggest that "go" decisions are made earlier on the approach to junctions than "stop" decisions. That is, in a manner which is highly adaptive, drivers decide to continue with an approach to a junction when the lights have changed if they believe they are closer to the intersection than they actually are. They decide to stop when they are more capable of accurately estimating when the junction will be reached.

B2. Appreciation of Risk: Research by Groeger and Chapman, supported by General Accident and the Economic and Social Research Council, revealed that only some drivers know some of the types of traffic situations in which traffic accidents are more likely to occur (2.36, 2.99, 2.107). That is, earlier findings which suggest a systematic relationship between subjective and objective risk considerably oversimplify the relationship. This project also developed a laboratory based "judgements of traffic scenes" task which successfully discriminates between drivers of the same age with different amounts of traffic experience, and also those with equivalent amounts of driving experience who are different ages (2.108). Thus, for perhaps the first time in the driving domain, separate effects of age and driving experience were demonstrated in a laboratory task. This has had very substantial effects on the way we conceptualise drivers' understanding of danger and the risk-related decisions they take. Differences on the "judgements of traffic scenes" task appear to be corroborated by the way these individuals actually drive. Work is currently underway to adapt the task for possible use in detecting newly qualified drivers who may be particularly at risk (research funded by Department of Transport as part of our investigation of Early Learning of Driving Skills).

B3. Decision Making and Traffic Violations: A further strand of our research on drivers' decision making, and ways of influencing it, comprises our efforts within the CEC-funded DETER project. A novel decision-making task (Animated Interactive Driving Environment - AIDE) has been developed within this project and has been used to demonstrate that provision of normative information is effective in reducing some, but not all, types of traffic violation. Rather more powerful effects were found of simulated in-car feedback which indicated that a violation had been detected. These effects have recently been corroborated by studies of driving under real traffic conditions, while the normative feedback effects are the subject of a large-scale field trial currently underway in Norway (see 2.174).

C. The Role of Memory in Drivers' Assessments of Danger and Error

C1. Drivers' Memory for Risk: Although driving experience has long been considered an important variable in attempting to predict or explain behaviour, very little attempt has been made to study drivers' memory for information related to the task. Chapman and Groeger have, as part of the research project supported by General Accident and the Economic and Social Research Council, shown that feelings of risk dramatically affect drivers' memory for traffic situations (2.90, 2.159). A number of results have emerged from this programme of research which has involved both laboratory and on-road research and made use of free recall, cued recall and recognition paradigms. Overall, subjects show a bias towards recalling dangerous situations. When this is controlled for, it has been shown that where risk is to be anticipated, drivers are better able to recall and recognise risk-related information (2.159). The results of these studies further suggest that more risk-related details of risk-related objects are spontaneously recalled. These results have been interpreted in terms of "attention focusing" where, as is documented in the eyewitness testimony literature, subjects attend particularly to threat-related information during encoding. By comparison, aspects of the driving scene which are not related to dangers are recalled and recognised rather poorly when a perceived threat is present.

C2. Memory for Errors Committed and Criticism: In addition to continuing our interests in issues directly related to safety, attention has also devoted to the errors drivers commit and what they tell us about the skills involved in driving (2.13, 2.14, 2.33). Recently, this research has been linked to another main interest, i.e. the relationship between emotional arousal and recall of driving related information. Thus, for example, Groeger and Bekerian have shown that drivers are aware of having been criticised during a test-drive, but are unable to remember where or when that criticism was made.

The strength of this work on drivers' memory for aspects of the driving task lies in its use of standard recognition and recall paradigms, to some theoretical effect, to investigate memory in contexts where emotional arousal is naturally integral to the task. The findings are also important from a practical point of view. Drivers' poor recall of critical feedback strengthens our contention that normal driver-training practices need to be revised to take account of everyday learning and memory processes and phenomena. Similarly, it would seem that reports of accidents which rely on participants' and non-participants' recall of events are likely to be systematically biased towards certain types of information. Since most actuarial data on traffic accidents are based on just such information, the information on which theories of accident causation are based may be partially misleading.

D. Drivers' Self-Assessments of Skill

As part of the CEC funded Generic Intelligent Driver Support systems project, Groeger and Grande had the opportunity to develop methodologies for assessing the accuracy of, and influences upon, drivers' assessments of their own skills (2.165). The basic result, that drivers consider themselves better than novice drivers, was unsurprising in light of the frequently reported finding that drivers overestimate their ability. However, large sample sizes, the provision of feedback and evaluation of performance by a qualified driving instructor, and the use of repeated self assessments across different driving tasks revealed important and novel findings. Although drivers considered themselves better than novices, this opinion was not shared by an independent assessor. Feedback provided by the independent assessor reduced, but did not eliminate, this bias towards a positive view of one's own ability. Interestingly, in spite of this feedback's effect on self-assessments, there is remarkable stability in how drivers evaluate themselves over time (2.110). The consistency of this relationship is enhanced by greater amounts of traffic experience, which suggests that self-assessments in highly practised tasks may become rather resistant to feedback over time. Overall, this consistent view of one's driving is less positive depending on the numbers of reported accidents per mile driven in the recent past. There is also a strong suggestion that affective reactions to critical feedback depend, at least in part, on the consistency with which one's performance is viewed over time.

It appears that there is a consistent way of viewing one's performance which seems specific to a particular task, which strengthens with accident-free experience of that task, and which helps to predict which affective responses are likely to different types of feedback. This suggests that what we are observing is the operation of a "task-related self". This is important in theoretical terms, as is the possibility that self-assessment techniques may prove useful indirect tests of what has been learned in some, but not in all situations (see C1 above). That this task-related self is quite stable over time may help to explain why, as shown by investigations of drivers' recall of criticism (see C2 above), the effects of isolated, situation-specific feedback on one's driving may not be very enduring.

Conclusions

Over the past 40 years or so, the Unit has made a unique contribution to this field of research, and its publications have had a notable influence on the way in which behavioural problems in transport systems have been approached, particularly in the UK but also internationally. This long-term influence has been reinforced by Brown's continuing advisory contributions to national and international bodies concerned with transportation issues. His appointments as Extra-mural Professor of Traffic Science at the University of Groningen from 1988-91 and as an Honorary Research Fellow of the UK Transport Research Laboratory for 5 years from 1992 created more specific opportunities to inject the Unit's views on and findings from this field of research into larger and internationally respected laboratories elsewhere. In recent years, Groeger's research contributions to European programmes of work on advanced transport technology have considerably strengthened these broad influences of the Unit's approach to transport studies. For example, research on the relative risks of taxi and minicab travel in London (2.163, 2.164) will lead to legislative changes during the next session of Parliament.

The Unit's substantial contributions to this field of research were recognised by the award of an OBE to Brown in June 1991 for his "services to transport safety research"; by the 'Distinguished Foreign Colleague' Award presented to him by the Human Factors Society in 1990 for his "outstanding contributions to human factors"; and by the A.R. Lauer Traffic Safety Award presented to him in 1993 by the Human Factors and Ergonomics Society "in recognition of his efforts to stimulate psychologists' interest in driver behaviour and to convince traffic authorities of the importance of a driver-centred view of traffic problems". The point was made that "his work proved seminal in establishing that workload is an important concern in the driving domain". With Brown's retirement in April 1993 and Groeger's departure to an appointment at the University of Leeds in April 1994, the Unit's (and Council's) contributions to this field of research have effectively come to an end. In many respects this is regrettable, since there is now no institution in the UK with a comparable long-term commitment to researching attentional, perceptual and cognitive aspects of transport system design and usage in a way that bridges the gap between theory and application. The result is likely to be a concentration on short-term, highly specific, applied transport problems, the solution of which may go unreported in the mainstream psychological literature and hence fail to contribute substantially to the development of psychological theory.

PUBLICATIONS

Authored Books

2.1. HOUGHTON, G. (in press). The Production of Spoken Discourse: A Computational Model. New Jersey: Ablex.

Edited Books

2.2. Bermùdez, J., MARCEL, A.J. & Eilan, N. (Eds.) (in press). The Body and the Self. Cambridge, Mass.: MIT Press, Bradford Books.

2.3. Byerley, P.F., BARNARD, P.J. & MAY, J. (Eds.) (1993). Computers, Communication and Usability: Design Issues, Research and Methods for Integrated Services. Amsterdam: Elsevier Science Publishers, B.V.

Refereed Articles

2.4. BLANDFORD, A.E., Cross, N.G. & Scanlon, E. (1994). Computers and the development of design decision making skills. Computer and Education, 22, 45-56.

2.5. BLANDFORD, A. & YOUNG, R.M. (1993). In J.L. Alty, D. Diaper & S. Guest (Eds.), People and Computers VIII: Proceedings of the HCI '93 Conference (pp. 111-122). Cambridge: Cambridge University Press.

2.6. Bradshaw, J.A. & YOUNG, R.M. (1991). Integrating knowledge of purpose and knowledge of structure for design evaluation. IEEE Expert, 6, 33-40.

2.7. Brookhuis, K. & BROWN, I.D. (1992). Ergonomics and road safety. Impact of Science on Society, 165, 35-40.

2.8. BROWN, I.D. (1990). A down-to-earth view of proposals for a grand unification of traffic sciences (GUTS). Journal of the International Association of Traffic and Safety Sciences, 14, 109-111.

2.9. BROWN, I.D. (1990). Drivers' margins of safety considered as a focus for research on error. Ergonomics (Special Issue), 33, 1307-1314.
2.10. BROWN, I.D. (1993). Driver fatigue and road safety. Alcohol, Drugs and Driving, 9, (Nos. 3-4), 239-251.
2.11. BROWN, I.D. (in press). Conflicts between mobility, safety, and environmental preservation, expressed as a hierarchy of social dilemmas. Journal of the International Association of Traffic and Safety Sciences (IATSS Research).
2.12. BROWN, I.D. (in press). Driver fatigue. Human Factors.
2.13. BROWN, I. & GROEGER, J. (1990). A way with errors (Editorial). Ergonomics, (Special Issue), 33, 1183-1184.
2.14. BROWN, I.D. & GROEGER, J.A. (Eds.). (1990). Errors in the operation of transport systems. Ergonomics (Special Issue), 33. London: Taylor & Francis.
2.15. Chelazzi, L., Miller, E.K., DUNCAN, J. & Desimone, R. (1993). A neural base for visual search in inferior temporal cortex. Nature, 363, 345-347.
2.16. Currie, M., Mackay, P., Morgan, C., Runciman, W., Russell, W., SELLEN, A., Webb, R. & Williamson, J. (1993). The "wrong drug" problem in anaesthesia: An analysis of 2000 incident reports. Anaesthesia & Intensive Care, 21, 596-601.
2.17. Desimone, R. & DUNCAN, J. (in press). Neural mechanisms of selective visual attention. Annual Review of Neuroscience.
2.18. Driver, J., Baylis, G.C., GOODRICH, S.J. & Rafal, R.D. (in press). Axis-based neglect of visual shapes. Neuropsychologia .

2.19. DUFF, S.C. & BARNARD, P.J. (1990). Influencing behaviour via device representation: Decreasing performance by increasing instruction. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 61-66). Amsterdam: Elsevier Science Publishers, B.V.
2.20. DUNCAN, J. (1990). Goal weighting and the choice of behaviour in a complex world. Ergonomics, 33, 1265-1279.
2.21. DUNCAN, J. (1993). Coordination of what and where in visual attention. Perception, 22, 1261-1270.
2.22. DUNCAN, J. (1993). Similarity between concurrent visual discriminations: Dimensions and objects. Perception and Psychophysics, 54, 425-430.
2.23. DUNCAN, J. (1994). Selective attention in the primate visual system. Canadian Psychology, 35, 104-105.
2.24. DUNCAN, J. (in press). Cooperating brain systems in selective perception and action. In T. Inui & J.L. McClelland (Eds.), Attention and Performance XVI. Cambridge, MA: MIT Press.
2.25. DUNCAN, J. (in press). Target and nontarget grouping in visual search. Perception and Psychophysics.
2.26. DUNCAN, J. & Humphreys, G. (1992). Beyond the search surface: Visual search and attentional engagement. Journal of Experimental Psychology: Human Perception and Performance, 18, 578-588.
2.27. DUNCAN, J., WARD, R. & Shapiro, K. (1994). Direct measurement of attentional dwell time in human vision. Nature, 369, 313-315.
2.28. DUNCAN, J., Williams, P. & BROWN, I. (1991). Components of driving skill: Experience does not mean

expertise. Ergonomics, 34, 919-937.

2.29. DUNCAN, J., Williams, P., NIMMO-SMITH, I. & BROWN, I. (1993). The control of skilled behavior: Learning, intelligence, and distraction. In D.E. Meyer & S. Kornblum (Eds.), Attention & Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience (pp. 323-341). Cambridge, MA: The MIT Press.

2.30. GOODRICH, S., Henderson, L., Allchin, N. & Jeevaratnam, A. (1990). On the peculiarity of simple reaction time. Quarterly Journal of Experimental Psychology. 42A, 763-775.

2.31. GREEN, A.J.K. (1994). Interacting Cognitive Subsystems: A framework for considering the relationships between performance and knowledge representations. Interacting with Computers, 6, 61-85.

2.32. GREEN, A.J.K. & BARNARD, P.J. (1990). Iconic interfacing: The role of icon distinctiveness and fixed or variable screen location. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 457-462). Amsterdam: Elsevier Science Publishers, B.V.

2.33. GROEGER, J. (1990). Drivers' errors in and out of context. Ergonomics, (Special Issue), 33, 1423-1429.

2.34. GROEGER, J.A. (1990). Saying something different: Levels in the monitoring and repair of speech. Belfast Working Papers in Language and Linguistics, 10, 66-84.

2.35. GROEGER, J. (1994). The working memory man: An interview with Professor Alan D Baddeley, FRS. The Psychologist, 7, 58-59.

2.36. GROEGER, J.A. & CHAPMAN, P. (1990). Errors and bias in assessments of danger and frequency of traffic situations. Ergonomics (Special Issue), 33, 1349-1363.

2.37. Henderson, L. & GOODRICH, S.J. (1993). Simple reaction time and predictive tracking in Parkinson's disease: Do they converge on a single, fixed impairment of preparation? Journal of Motor Behaviour, 25, 89-96.

2.38. Henderson, L., Kennard, C., Crawford, T., Day, S., Everett, B., GOODRICH, S., Jones, F. & Park, D.M. (1991). Scales for rating motor impairment in Parkinson's disease: Studies of reliability and convergent validity. Journal of Neurology, Neurosurgery and Psychiatry, 54, 18-24.

2.39. HOWES, A. (1994). A model of the acquisition of menu knowledge by exploration. In B. Adelson, S. Dumais & J. Olson (Eds.), Human Factors in Computing Systems ("Celebrating Interdependence", Proceedings of CHI '94 Conference, Boston, MA, 1994) (pp. 445-451). New York: ACM.

2.40. HOWES, A. & YOUNG, R.M. (1991). Predicting the learnability of task-action mappings. In S.P. Robertson, G.M. Olson & J.S. Olson (Eds.), Reaching through Technology - CHI '91 Conference Proceedings: Human Factors in Computing Systems (pp. 113-118). New Orleans, Louisiana: Addison-Wesley.

2.41. LAVIE, N. & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. Perception & Psychophysics, 55, 1-15.

2.42. LAVIE, N. (in press). Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology: Human Perception & Performance.

2.43. LEE, W-O. (1992). The effects of skill development and feedback on action slips. In A. Monk, D. Diaper & M.D. Harrison (Eds.), People and Computers VII (pp. 73-86). Cambridge: Cambridge University Press.

2.44. LEE, W-O. (1993). Adapting to interface resources and circumventing interface problems: Knowledge development in a menu search task. In J.L. Alty, D. Diaper & S. Guest (Eds.), People and Computers VIII: Proceedings of the HCI'93 Conference (pp. 61-77) Cambridge University Press.

2.45. LEE, W-O. & BARNARD, P.J. (1993). Precipitating change in system usage by function revelation and problem reformulation. In J.L. Alty, D. Diaper & S. Guest (Eds.), People and Computers VIII: Proceedings of the HCI'93 Conference (pp. 35-47). Cambridge University Press.

2.46. MacLean, A., Bellotti, V. & YOUNG, R. (1990). What rationale is there in design? In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 207-212). Amsterdam: Elsevier Science Publishers, B.V.

2.47. MacLean, A., Bellotti, V., YOUNG, R., & Moran, T. (1991). Reaching through analogy: A design rationale perspective on roles of analogy. In S. Robertson, G. Olson & J. Olson (Eds.), CHI '91 Conference Proceedings (pp. 167-172). New York: ACM.

2.48. MacLean, A., YOUNG, R., Bellotti, V.M.E. & Moran, T.P. (1991). Questions, options, and criteria: Elements of design space analysis. Human-Computer Interaction, 6, 201-250.

2.49. MARCEL, A.J. (1990). What does it mean to ask whether cognitive skills are prerequisite for learning to read and write? A response to Cossu and Marshall. Cognitive Neuropsychology, 7, 41-48.

2.50. MAY, J., BARNARD, P.J. & BLANDFORD, A. (1993). Using structural descriptions of interfaces to automate the modelling of user cognition. User Modelling and User Adapted Interaction, 3, 27-64.

2.51. MAY, J., BARNARD, P.J., Boecker, M. & GREEN, A.J. (1990). Characterising structural and dynamic aspects of the interpretation of visual interface objects. In ESPRIT '90 Conference Proceedings (pp. 819-834), (Brussels, November 1990), Dordrecht: Kluwer Academic Publishers.

2.52. MAY, J., TWEEDIE, L. & BARNARD, P.J. (1993). Modelling user performance in visually based interactions. In J.L. Alty, D. Diaper & S.P. Guest (Eds.), People and Computers VIII: Proceedings of the HCI '93 Conference (pp. 95-110). Cambridge: Cambridge University Press.

2.53. Michon, J.A., Kuiken, M.J. & GROEGER, J.A. (1992). Smartening road traffic: The role of GIDS. IATSS Research, 16, 106-113.

2.54. Payne, S.J. & HOWES, A. (1992). A task-action trace for exploratory learners. Behaviour and Information Technology, 11, 63-70.

2.55. Payne, S.J., HOWES, A. & Hill, E. (in press). Conceptual instructions derived from an analysis of device models. International Journal of Human-Computer Interaction.

2.56. Payne, S.J., Squibb, H. & HOWES, A. (1991). The nature of device models: The yoked state space hypothesis and some experiments with text editors. Human Computer Interaction, 5, 415-444.

2.57. Rieman, J., Lewis, C., YOUNG, R.M. & Polson, P.G. (1994). "Why is a raven like a writing desk?" Lessons in interface consistency and analogical reasoning from two cognitive architectures. In B. Adelson, S. Dumais & J. Olson (Eds.), Human Factors in Computing Systems ("Celebrating Interdependence", Proceedings of CHI '94 Conference, Boston, MA, 1994) (pp. 438-444). New York: ACM.

2.58. ROBERTSON, I., Tegnèr, R., GOODRICH, S. & Wilson, C. (in press). Walking trajectory and hand movements in unilateral left neglect: A vestibular hypothesis. Neuropsychologia.

2.59. Runciman, W.B., SELLEN, A.J., Webb, R.K., Williamson, J.A., Currie, M., Morgan, C. & Russell, W.J. (in

press). Errors, incidents and accidents in anaesthesia. Anaesthesia and Intensive Care.
2.60. SELLEN, A.J. (in press). Detection of everyday errors. Applied Psychology: An International Review (Special Issue on Error Detection edited by D. Zapf & J. Reason).
2.61. WARD, R., GOODRICH, S.J. & Driver, J. (in press). Grouping reduces visual extinction: Neuropsychological evidence for weight-linkage in visual selection. Visual Cognition.
2.62. Williamson, J., Webb, R., SELLEN, A., Runciman, W. & Van Der Walt, J. (1993). Human failure: An analysis of 2000 incident reports. Anaesthesia & Intensive Care, 21, 678-683.
2.63. WING, A.M., GOODRICH, S., VIRJI-BABUL, N., Jenner, J.R. & CLAPP, S. (1993). Balance evaluation in hemiparetic stroke patients using lateral forces applied to the hip. Archives of Physical Medicine and Rehabilitation, 74, 292-299.
2.64. YOUNG, R. M. (1994) The unselected window scenario: Analysis based on the Soar cognitive architecture. In G. D. Abowd (Ed), Proceedings of the CHI'94 Research Symposium.
2.65. YOUNG, R. M. & Abowd, G. D. (1994) Multi-perspective modelling of interface design issues: Undo in a collaborative editor. In People and Computers IX: Proceedings of the Conference on Human-Computer Interaction. Cambridge University Press.
2.66. YOUNG, R.M. & BARNARD, P.J. (1991). Signature tasks and paradigm tasks: New wrinkles on the scenarios methodology. In D. Diaper & N. Hammond (Eds.), People and Computers VI: Proceedings of the HCI '91 Conference (pp. 91-101). Cambridge: Cambridge University Press.
2.67. YOUNG, R.M., HOWES, A. & WHITTINGTON, J. (1990). A knowledge analysis of interactivity. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 115-120). Amsterdam: Elsevier Science Publishers, B.V.
2.68. YOUNG, R.M. & WHITTINGTON, J. (1990). Using a knowledge analysis to predict conceptual errors in text-editor usage. In J.C. Chew & J. Whiteside (Eds.), Empowering People. Human Factors in Computing Systems (pp.91-97), (CHI '90 Conference Proceedings, Special Issue of the SIGCHI Bulletin). Seattle, Washington: ACM Press.
Submitted
2.69. BARNARD, P.J., MAY, J & Salber, D. Deixis and points of view in media spaces: An empirical gesture. (manuscript submitted to Behaviour and Information Technology).
2.70. BLANDFORD, A.E., Harrison, M.D. & BARNARD, P.J. Understanding the properties of interactions. (Manuscript submitted to International Journal of Human Computer Studies)
2.71. BOURKE, P. A. Measuring attentional demand. (Manuscript submitted to Quarterly Journal of Experimental Psychology).
2.72. BOURKE, P. A., DUNCAN, J., & NIMMO-SMITH, I. A general factor involved in dual task performance decrement. (Manuscript submitted to Quarterly Journal of Experimental Psychology).
2.73. DUNCAN, J., BURGESS, P., & EMSLIE, H. Fluid intelligence after frontal lobe lesions. (Manuscript submitted to Neuropsychologia).
2.74. DUNCAN, J., EMSLIE, H., Williams, P. & Johnson, R. Intelligence and the frontal lobe: The organization of goal-directed behavior. (Manuscript submitted to Cognitive Psychology).

2.75. HOWES, A. & YOUNG, R. M. A learning and performance model of display-based task-action mapping. (Manuscript submitted to Cognitive Science)

2.76. Humphreys, G.W., Romani, C., Olson, S., Riddoch, M.J. & DUNCAN, J. Non-spatial extinction following lesions of the parietal lobe in humans. (Manuscript submitted to Nature).

2.77. MARCEL, A.J. (a) The influence of vision on tactile sensation. (Manuscript submitted to Perception)

2.78. MARCEL, A.J. (b) Blindsight: A problem of visual consciousness or visual function? (Manuscript submitted to Brain)

2.79. MAY, J. & BARNARD P.J. The case for supportive evaluation during design. (Manuscript submitted to Interacting with Computers).

Invited Chapters and Commentaries

2.80. BARNARD, P.J. (1991). Applied cognitive psychology: Research for human-computer interaction. In A.C. Downton (Ed.), Engineering the Human-Computer Interface (pp. 28-61). McGraw-Hill.

2.81. BARNARD, P.J. (1991). Bridging between basic theories and the artifacts of human-computer interaction. In J.M. Carroll (Ed.), Designing Interaction: Psychology at the Human-Computer Interface (pp. 103-127). Cambridge: Cambridge University Press.

2.82. BARNARD, P. J. (1991). The contributions of applied cognitive psychology to the study of human-computer interaction. In B. Shackel & S. Richardson (Eds.), Human Factors for Informatics Usability (pp. 151-182). Cambridge: Cambridge University Press.

2.83. BARNARD, P. (in press). The contributions of applied cognitive psychology to the study of human-computer interaction. In R. Baecker, J. Grudin, W. Buxton & S. Greenberg, S. (Eds.), Readings in Human-Computer Interaction, Second Edition, Los Altos, CA: Morgan Kaufmann. (Reproduction of APU 2205)

2.84. BARNARD, P.J. & MAY, J. (1993). Cognitive modelling for user requirements. In P.F. Byerley, P.J. Barnard & J. May (Eds.), Computers, Communication and Usability: Design Issues, Research and Methods for Integrated Services (pp. 101-145). Amsterdam: Elsevier Science Publishers, B.V.

2.85. BLANDFORD, A., Harrison, M.D. & BARNARD, P.J. (1993). Integrating user requirements and system specification. In P.F. Byerley, P.J. Barnard & J. May (Eds.), Computers, Communication and Usability: Design Issues, Research and Methods for Integrated Services (pp. 165-196). Amsterdam: Elsevier Science Publishers, B.V.

2.86. BROWN, I.D. (1990). Accident reporting and analysis. In J.R. Wilson & E.N. Corlett (Eds.), Evaluation of Human Work: A Practical Ergonomics Methodology (pp. 755-778). London: Taylor and Francis Ltd.

2.87. BROWN, I.D. (1990). On the social dilemma of motorway safety. In T. Benjamin (Ed.), Driving Behaviour in a Social Context (pp.663-670). Caen: Paradigme.

2.88. BROWN, I.D. (1991). Prospects for improving road safety during the 1990's. In Ergonomics, Safety and Health: Perspectives for the Nineties. Leuven, Belgium: Leuven University Press.

2.89. BROWN, I.D. (1993). Methodological issues in driver fatigue research. In Driver Impairment, Fatigue, and Driving Simulation. Applecross, Western Australia: Promaco Conventions Pty Ltd.

2.90. CHAPMAN, P.R. & GROEGER, J.A. (1992). Subjective risk and subsequent memory. In G.B. Grayson

(Ed.), Behavioural Research in Road Safety: II (pp. 44-52). Crowthorne, UK: Transport Research Laboratory.
2.91. Clegg, G., Warr, P., GREEN, T., Monk, A., Kemp, N., Allison, G. & Lansdale, M. (Eds.). (1988). People and Computers: How to Evaluate your Company's New Technology. Chichester: Ellis Horwood Ltd.
2.92. Desimone, R., Chelazzi, L., Miller, E.K. & DUNCAN, J.D. (in press). Neural mechanisms for memory-guided visual search. In C. Nothdurft (Ed.), Structural and Functional Organization of the Neocortex. Springer-Verlag.
2.93. Desimone, R., Chelazzi, L., Miller, E.K. & DUNCAN, J. (in press). Neuronal mechanisms of visual attention. In T. Papathomas (Ed.), Linking Psychophysics, Neurophilosophy, and Computational Vision. Cambridge, MA.: MIT Press.
2.94. DUFF S.C. (1992). Mental models as multi-record representations. In Y. Rogers, A. Rutherford & P. Bibby (Eds.), Models in the Mind: Theory, Perspective and Applications (pp. 172-186). London: Academic Press.
2.95. DUNCAN, J. (1993). Selection of visual information in the control of behaviour. In A.D. Baddeley & L. Weiskrantz (Eds.), Attention: Selection, Awareness and Control: A Tribute to Donald Broadbent (pp. 53-71). Oxford: Clarendon Press.
2.96. DUNCAN, J. (in press). Attention, intelligence and the frontal lobes. In M.S. Gazzaniga (Ed.), The Cognitive Neurosciences. MIT Press.
2.97. Eilan, N., MARCEL, A.J. & Bermùdez, J. (in press). Self-consciousness and the body: Interdisciplinary issues. In J. Bermùdez, A.J. Marcel & N. Eilan (Eds.), The Body and the Self. Cambridge, Mass.: MIT Press, Bradford Books.
2.98. Gothelp, H., Farber, B., GROEGER, J.A. & Labiale, G. (1993). Driving: Task and environment. In J.A. Michon (Ed.), Generic Intelligent Driver Support (pp. 19-32). London: Taylor & Francis.
2.99. GROEGER, J.A. (1990). Concepts of danger: The unknown risks we run. In H. Bohm (Ed.), Psychological Statistics and Models of Accidents in Traffic Systems (pp.59-72). Bremen: Commission of the European Communities.
2.100. GROEGER, J.A. (1991). Acquiring and retaining driving skills. In M.J. Kuiken & J.A. Groeger (Eds.), Report on Feedback Requirements and Performance Differences of Drivers (pp. 3-14). Deliverable ADA2, DRIVE Project 1041: Generic Intelligent Driver Support Systems, Traffic Research Center, University of Groningen, The Netherlands.
2.101. GROEGER, J.A. (1991). Meeting drivers' needs for adaptive support: Personalised Support and Learning Module (PSALM). In M.J. Kuiken & J.A. Groeger (Eds.), Report on Feedback Requirements and Performance Differences of Drivers (pp. 89-94). Deliverable ADA2, DRIVE Project 1041: Generic Intelligent Driver Support Systems, Traffic Research Centre, University of Groningen, The Netherlands.
2.102. GROEGER, J.A. (1993). Degrees of freedom and the limits of learning: Support needs of inexperienced motorists. In A.M. Parkes & S. Franzen (Eds.), Driving Future Vehicles (pp. 77-88). London: Taylor & Francis.
2.103. GROEGER, J.A. (1993). Driving research at crossroads. In J.A. Santos (Ed.), Human Factors in Road Traffic (pp. 47-68). Lisbon: Escher.
2.104. GROEGER, J.A. (in press). Activities of lone watchkeepers on an ocean-going voyage. In H. Bohm (Ed.), Psychological Care for Operators Working in High Tech Transport Systems in Isolated Conditions. Bremen:

Commission of the European Communities.
2.105. GROEGER, J.A. (in press). Degrees of freedom and the limits of learning: Support needs of inexperienced motorists. In A.W. Parkes & S. Fransen (Eds.), Driving Future Vehicles. London: Taylor & Francis.
2.106. GROEGER, J.A., Alm, H., Haller, R. & Michon, J.A. (1993). Acceptance of intelligent in-car devices. In J.A. Michon (Ed.), Generic Intelligent Driver Support (pp. 217-228). London: Taylor & Francis.
2.107. GROEGER, J.A. & CHAPMAN, P.R. (1991). The unknown risks we run: Feelings of danger and estimates of accident frequency when driving. In G.B. Grayson & J.F. Lester (Eds.), Behavioural Research in Road Safety (pp. 131-138). Crowthorne: Transport and Road Research Laboratory.
2.108. GROEGER, J.A. & CHAPMAN, P.R. (1992). Developing an understanding of danger: Contributions of experience and age. In G.B. Grayson (Ed.), Behavioural Research in Road Safety II (pp. 37-43). Crowthorne, UK: Transport Research Laboratory.

2.109. GROEGER, J.A. & GRANDE, G.E. (1991). Support received during drivers' training. In M.J. Kuiken & J.A. Groeger (Eds.), Report on Feedback Requirements and Performance Differences of Drivers (pp. 15-42). Deliverable ADA2, DRIVE Project 1041: Generic Intelligent Driver Support Systems. Groningen, The Netherlands: Traffic Research Center, University of Groningen.
2.110. GROEGER, J.A. & GRANDE, G.E. (in press). Psychological and performance correlates of self-assessed skill. In G.B. Grayson (Ed.), Behavioural Research in Road Safety III. Crowthorne, UK: Transport Research Laboratory.
2.111. GROEGER, J.A. & Kuiken, M.J. (1993). GIDS functions: Adaptive support. In J.A. Michon (Ed.), Generic Intelligent Driver Support (pp. 129-135). London: Taylor & Francis.
2.112. HOUGHTON, G. (1990). The problem of serial order: A neural network model of sequence learning and recall. In R. Dale, C. Mellish & M. Zock (Eds.), Current Research in Natural Language Generation (pp. 287-319). London: Academic Press.
2.113. HOUGHTON, G. & Tipper, S.P. (in press). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. Carr (Eds.), Inhibitory Mechanisms in Attention, Memory and Language. London: Academic Press.
2.114. HOWES, A. (in press). An introduction to cognitive modelling in human-computer interaction. In A. Monk & N. Gilbert (Eds.), Perspectives on Human-Computer Interaction. Academic Press.
2.115. HOWES, A. (in press). Cognitive modelling: Experiences in human-computer interaction. In T.L. Nyerges (Ed.), Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems. The Netherlands: Kluwer Academic Publishers.
2.116. MARCEL, A.J. (1992). The personal level in cognitive rehabilitation. In N. von Steinbüchel, D.Y. von Cramon & E. Pöppel (Eds.), Neuropsychological Rehabilitation (pp. 155-168). Berlin: Springer-Verlag.
2.117. MARCEL, A.J. (in press). Bodily experience and self: Explanatory priority. In J. Bermùdez, A.J. Marcel & N. Eilan (Eds.), The Body and the Self. Cambridge, Mass.: MIT Press, Bradford Books.
2.118. MAY, J., Byerley, P.F., Denley, I., Hill, B., Adamson, S. Patterson, P. & Hedman, L.R. (1993). The

enabling states method. In P.F. Byerley, P.J. Barnard & J. May (Eds.), Computers, Communication and Usability: Design Issues, Research and Methods for Integrated Services (pp. 247-290). Amsterdam: Elsevier Science Publishers, B.V.

2.119. Newell, A., YOUNG, R.M. & Polk, T. (1993). The approach through symbols. In D.E. Broadbent (Ed.), The Simulation of Human Intelligence (pp. 33-70). Oxford: Blackwell.

2.120. Wilson, M., BARNARD, P. & MacLean, A. (1990). An investigation of the learning of a computer system. In P. Falzon (Ed.), Cognitive Ergonomics, Understanding Learning and Designing Human-Computer Interaction (pp. 151-172). London: Academic Press Ltd.

2.121. YOUNG, R.M. (in press). Functionality matters: Capacity constraints and Soar. In D. Steier & T. Mitchell (Eds.), Mind Matters: Contributions to Cognitive and Computer Science in Honor of Allen Newell. Hillsdale, N.J.: Lawrence Erlbaum Associates.

2.122. YOUNG, R.M. & BARNARD, P.J. (1992). Multiple uses of scenarios: A reply to Campbell. SIGCHI Bulletin, 24, p.10.

Conference Proceedings

2.123. BARNARD, P.J. (1993). Modelling users, systems and design spaces (ESPRIT Basic Research Action 3066). In M.J. Smith & G. Salvendy (Eds.), Human-Computer Interaction: Applications and Case Studies. Advances in Human Factors/Ergonomics Vol. 19A: Proceedings of HCI International 1993 (pp. 331-336). Amsterdam: Elsevier Science Publishers B.V.

2.124. BARNARD, P.J. & Harrison, M.D. (1992). Towards a framework for modelling human-computer interactions. In J. Gornostaev (Ed.), Proceedings of the International Conference on Human Computer Interaction, EWHCI '92 (pp. 189-196). Moscow: ICSTI.

2.125. Bradshaw, J.A. & YOUNG, R.M. (1991). Evaluating the behaviour of the BAs 146 hydraulic system using the Doris system. In B. Neumann (Ed.), Tenth European Conference on Artificial Intelligence (pp. 739-743). John Wiley & Sons Ltd.

2.126. CHURCHILL, E.F. & YOUNG, R.M. (1991). Modelling representations of device knowledge in Soar. In L. Steel & B. Smith (Eds.), AISB91: Proceedings of the Eighth Conference of the Society for the Study of Artificial Intelligence and Simulation of Behaviour (pp. 248-255). London: Springer-Verlag.

2.127. BROWN, I.D. (1991). Highway hypnosis: Implications for road traffic researchers and practitioners. In A.G. Gale, I.D. Brown, C.M. Haslegrave, S.P. Taylor & I. Moorhead (Eds.), Vision in Vehicles III (pp. 459-466). Amsterdam: Elsevier Science Publishers B.V. (North-Holland).

2.128. BROWN, I.D. (1991). Introduction to DRIVE Project V1041: Generic Intelligent Driver Support (GIDS). In Y. Queinnec & F. Daniellou (Eds.), Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association (pp. 1533-1535), (Paris, 1991). London: Taylor & Francis.

2.129. BROWN, I.D. (1991). Overview of the Conference and the Road to VIV IV. In A.G. Gale et al. (Eds.), Vision in Vehicles III (pp. 481-486). Amsterdam: Elsevier Science Publishes B.V. (North-Holland.

2.130. BROWN, I.D. (in press). Reducing accident risk for the heavy goods vehicle driver. In Proceedings of the 12th World Congress of the International Association of Accident and Traffic Medicine (Helsinki, Finland, 23-25 June 1992).

2.131. BROWN, I.D. (in press). The case for 'long-term care' in driver training. In Proceedings of AGAM Nederland Conference on 'New Perspectives on Integrated Traffic Training in Europe' (Best, The Netherlands, 6-8 May, 1992).
2.132. Gale, A.G., BROWN, I.D., Haslegrave, C.M., Kruysse, H.W. & Taylor, S.P. (Eds.). (1993). Vision in Vehicles IV. Amsterdam: North Holland.
2.133. Gale, A.G., BROWN, I.D., Haslegrave, C.M., Moorhead, I. & Taylor, S.P. (Eds.). (1991). Vision in Vehicles III. Amsterdam: North-Holland.
2.134. GROEGER, J.A. (1991). Learning from learning: Principles for supporting drivers. In Proceedings of the 24th ISATA International Symposium on Automotive Technology and Automation (pp. 703-709). Croydon: Automotive Automation.
2.135. GROEGER, J.A. (1991). Supporting training drivers and the prospects for later learning. In Advanced Telematics in Road Transport: Proceedings of DRIVE Conference, Vol. 1 (pp. 314-330), (February 4-6 1991), Amsterdam: Elsevier.
2.136. GROEGER, J.A. (in press). Introducing ADA: Adaptation and Instructional Support for Drivers. In R. Haller (Ed.), Proceedings of Seminar on MMI Basic Research (Karlsruhe, Germany, April 17-18, 1991). Brussels: Prometheus Office.
2.137. GROEGER, J.A. & Cavallo, V. (1991). Judgements of time-to-collision and time-to-coincidence. In A.G. Gale et al. (Eds.), Vision in Vehicles III (pp.27-34). Elsevier Science Publishers B.V. (North-Holland).
2.138. GROEGER, J.A. & CLEGG, B.A. (1993). What is learned by drivers during training, and how can we improve it? In W. Barta (Ed.), Proceedings of "Novice Driver Education" (Edmonton, April 22-23, 1993). Edmonton: The University of Alberta and Alberta Motor Association.
2.139. GROEGER, J.A. & GRANDE, G.E. (1991). Too little too soon: Limitations of training and the need for continuing driver support. In Y. Queinnec & F. Daniellou (Eds.), Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association (pp. 1492-1494), Paris, 1991. London: Taylor & Francis.
2.140. GROEGER, J.A., GRANDE, G. & BROWN, I.D. (1991). Accuracy and safety: Effects of different training procedures on a time-to-coincidence task. In A.G. Gale et al. (Eds.), Vision in Vehicles III (pp.35-43). Elsevier Science Publishers B.V. (North-Holland).
2.141. GROEGER, J.A. & Kuiken, M.J. (1993). Performance histories and adaptive instructional support. In Advanced Transport Telematics (Proceedings of the Technical Days Volume II) (pp. 340-343) (Brussels, March 8-10, 1993). Commission of the European Communities.
2.142. Harrison, M.D. & BARNARD, P.J. (1993). On defining requirements for interactions. In A. Finkelstein (Ed.), Proceedings of the IEEE International Workshop on Requirements Engineering (pp. 50-54). New York: IEEE.

2.143. Harrison, M.D., BLANDFORD, A.E. & BARNARD, P.J. (1994). The requirements engineering of user freedom. In F. Paterno (Ed.), The Design, Specification and Verification of Interactive Systems: Proceedings of the Eurographics Workshop (pp. 181-194), (Carrara, Italy, 8-10 July). Pisa: CNUCE-CNR.

2.144. HOWES, A. (1993). Recognition-based problem solving. In Proceedings of the 15th Annual Conference of the Cognitive Science Society (pp. 551-556). (Boulder, Colorado, 1993). Hillsdale, N.J.: Lawrence Erlbaum Associates.

2.145. Kuiken, M.J. & GROEGER, J.A. (in press). Reducing drivers' speeds on bends: Differential effects of feedback. In A.G. Gale, I.D. Brown, C.M. Haslegrave, I. Moorhead & S. Taylor (Eds.), Vision in Vehicles III. Amsterdam: Elsevier Science Publications.

2.146. MacLean, A., YOUNG, R., Bellotti, V. & Moran, T. (1992). Design space analysis: Bridging from theory to practice via design rationale. In Proceedings of Esprit Conference 1991 (pp. 720-730) (Brussels, Nov 25-29, 1991), CEC.

2.147. MARCEL, A.J. (1993). Slippage in the unity of consciousness. In Ciba Foundation Symposium No. 174 - Experimental and Theoretical Studies of Consciousness. Chichester: John Wiley & Sons.

2.148. MARCEL, A.J. (1994). What is relevant to the unity of consciousness? In C. Peacocke (Ed.), Philosophy of Mind: Proceedings of the British Academy, Vol. 83.

Technical Reports and Theses

2.149. Allsop, R.E., BROWN, I.D., GROEGER, J.A., & Robertson, S.A. (1991). Approaches to modelling driver behaviour at actual and simulated traffic signals. Contractor Report 264, Transport and Road Research Laboratory, Department of Transport. Crowthorne, Berks: Transport and Road Research Laboratory.

2.150. BARNARD, P.J. (Ed.) (1990). Assimilating Models of Designers, Users and Systems (AMODEUS), Periodic Progress Report No. 1, and Associated Deliverables. Brussels: CEC, September.

2.151. BARNARD, P.J. (Ed.) (1993). AMODEUS 2: ESPRIT Basic Research Action 7040, Periodic Progress Report 1, and Associated Scientific Deliverables. Brussels: CEC.

2.152. BARNARD, P.J. (Ed.) (1994). AMODEUS 2: ESPRIT Basic Research Action 7040, Periodic Progress Report 2, and Associated Scientific Deliverables. Brussels: CEC, July.

2.153. BARNARD, P.J., BLANDFORD, A.E. & MAY. J. (1992). Demonstration of expert system capability. Documentation to support and accompany D19, Constituent part of scientific deliverables associated with APU 2962, pp 136.

2.154. BARNARD, P.J., Coutaz, J., Hammond, N., Harrison, M., Jørgensen, A., MacLean, A. & YOUNG, R. (1992). AMODEUS ESPRIT Basic Research Action 3066 Final Report, D23. Brussels: CEC.

2.155. BARNARD, P.J. & Harrison, M.D. (Eds.) (1991). Assimilating Models of Designers, Users and Systems (AMODEUS), Periodic Progress Report No. 2, and Associated Scientific Deliverables. Brussels: CEC, September.

2.156. BARNARD, P.J. & MAY, J. (1993). Real time blending of data streams: A key problem for the cognitive modelling of multimodal systems. AMODEUS working Paper UM/WP 10; May 1993, pp 25. Constituent part of scientific deliverable D2 associated with APU 2963.

2.157. BOURKE, P.A. (1993). A general factor in dual task performance decrement. Unpublished PhD Thesis, University of Cambridge.

2.158. BROWN, I.D. (1992). Fatigue and driving. Unpublished review, commissioned by the Department of Transport via the Medical Commission on Accident Prevention and submitted by the author in January, 1992.

2.159. CHAPMAN, P.R. (1992). Subjective risk and memory for driving situations. Unpublished PhD Thesis,

University College London.
2.160. CHURCHILL, E.F. (1993). Models of models: Cognitive, computational and empirical investigations of learning a device. Unpublished PhD Thesis, University of Cambridge.
2.161. DUFF, S.C. (1990). Task and device representations in the use of interactive systems. Unpublished PhD Thesis, University of Cambridge.
2.162. Duke, D., Duce, D., BARNARD, P.J, Harrison, M.D. & MAY, J. (1994). On the integration of cognitive and system models, AMODEUS, ID/WP26, pp. 21. Constituent part of the D7 scientific deliverable associated with APU 3122.
2.163. GROEGER, J.A. (1991). Expectations and experience of taxi and minicab use. Technical Report to Department of Transport on CON 3030. London: The Suzy Lamplugh Trust..
2.164. GROEGER, J.A. (1991). Relative risks of taxi and minicab travel. Consultant's Report to Department of Transport on CON 3030. London: The Suzy Lamplugh Trust.
2.165. GROEGER, J.A. & GRANDE, G.E. (1992). Meeting the support requirements of drivers with different levels of traffic experience: An evaluation. Deliverable ADA3, DRIVE Project 1041: Generic Intelligent Driver Support Systems. The Netherlands: University of Groningen, Traffic Research Centre.
2.166. GROEGER, J.A., GRANDE, G.E. & BROWN, I.D. (in press). Decisions at simulated traffic signals. Report to the Transport and Road Research Laboratory, (CON/98 34/35).
2.167. GROEGER, J.A. & Kuiken, M.J. (1992). Instructional support: Scenario and support definition. Deliverable 211, DRIVEII Project V2004: Application of a Real-time Intelligent Aid for Driving and Navigation Enhancement (ARIADNE). Rover Group Ltd., U.K.
2.168. GROEGER, J.A. & Kuiken, M.J. (1993). Effects of instructional sets. Deliverable 212, DRIVE II Project V2004: Application of a Real-time Intelligent Aid for Driving and Navigation Enhancement (ARIADNE). Rover Group Ltd., U.K.
2.169. GROEGER, J.A., Kuiken, M., GRANDE, G.E., Miltenburg, P., BROWN, I.D. & Rothengatter, J.A. (1990). Preliminary design specifications for appropriate feedback provision to drivers with differing levels of traffic experience. Deliverable ADA1, DRIVE Project 1041: Generic Intelligent Driver Support Systems. Traffic Research Centre, University of Groningen.
2.170. Kuiken, M.J. & GROEGER, J.A. (1991). Report on Feedback Requirements and Performance Differences of Drivers. Deliverable ADA2, DRIVE Project 1041: Generic Intelligent Driver Support Systems. Traffic Research Center, University of Groningen, The Netherlands.
2.171. LEE, W-O. (1993). Incremental change in the development of expertise in using interactive systems. Unpublished PhD Thesis, University of Cambridge.
2.172. MAY, J. (1993). The part-whole problem in perception. Electronic document, AMODEUS Pres 4, October; pub/amodeus/usemod/pres4.hqx @ ftp.mrc-apu.cam.ac.uk
2.173. MAY J. & BARNARD, P.J. (1993). Modelling the user's interpretation of dynamic displays. AMODEUS: Working paper UM/WP9; May 1993, pp.28. Constituent part of scientific deliverable D2 associated with APU 2963.
2.174. Muskaug, R. & GROEGER, J.A. (1992). On-site Tutoring and Enforcement Systems. Deliverable 120,

DRIVE Project V2009: Detection, Enforcement and Tutoring for Error Reduction (DETER). The Netherlands: University of Groningen, Traffic Research Centre.
2.175. Piersma, E.H., Kuiken, M.J., van Winsum, W., GROEGER, J.A., Stove, A.G. & Verwey, W.B. (1992). Specification of the Requirements for a Second Generation GIDS System Prototype. Deliverable 01, DRIVE II Project 2004: Application of a Real-time Intelligent Aid for Driving and Navigation Enhancement (ARIADNE). Rover Group, U.K.
2.176. PRICE, M.C. (1991). Processing and awareness of masked stimuli. Unpublished PhD Thesis, University of Cambridge.
2.177. TWEEDIE, L., BARNARD, P.J. & MAY J. (1993). AnimICS v 5.0. Electronic document, pub/amodeus/usemod/AnimICS_5.hqx @ ftp.mrc-apu.cam.ac.uk
2.178. YOUNG, R. M. & WHITTINGTON, J. E. (1990) Interim report on means-ends analysis in Soar. ESPRIT Basic Research Action 3066, Amodeus Project Document RP5/WP3 (also in Deliverable D5).
Dissemination
2.179. BARNARD, P.J. (1990). Research on Human-Computer Interaction at the MRC Applied Psychology Unit. In J.C. Chew & J. Whiteside (Eds.), CHI '90 Conference Proceedings: Human Factors in Computing Systems (pp. 379-380), (Special issue of the SIGCHI Bulletin). Seattle, Washington: ACM Press.
2.180. TWEEDIE, L. & BARNARD, P.J. (1992). The Interactive Talk: A new tool for presenting complex theory. Psychology Software News, 3, 43-45.
REFERENCES TO OTHER WORK
Allport, D.A. (1980). Attention and performance. In G. Claxton (Ed.), Cognitive Psychology: New Directions (pp. 112-153). London: Routledge and Kegan Paul.
BADDELEY, A.D., Bressi, S., Della Sala, S., Logie, R. & Spinnler, H. (1991). The decline of working memory in Alzheimer's Disease: A longitudinal study. Brain, 114, 2521-2542.
Bahrick, L.E. (1988). Intermodal learning in infancy: Learning on the basis of two kinds of invariant relations in audible and visible events. Child Development, 59, 197-209.
BARNARD, P.J. (1993). Applying cognitive theory: Human-computer interaction as a case study. Invited Lecture presented at the BPS Cognitive Section Annual Conference (Cambridge, England. September).
BARNARD, P.J. (1994). Unpacking the central executive functions. Paper presented at the International Conference on Working Memory (Cambridge, England, July 20-22nd).
BARNARD, P., Wilson, M. & MacLean, A. (1988). Approximate modelling of cognitive activity with an expert system: A theory-based strategy for developing an interactive design tool. The Computer Journal, 31, 445-456.
BLANDFORD, A.E. (1993). An agent-theoretic approach to computer participation in dialogue. International Journal of Man-Machine Studies, 39, 965-998
BLANDFORD, A.E. (1993). Applying the WOM to WOMBAT: evaluation of a tool to support learning about design evaluation. Design Studies, 14 228-246
BLANDFORD, A.E. (in press, a). Teaching through collaborative problem solving. Journal of Artificial Intelligence in Education.
BLANDFORD, A.E. (in press, b). Deciding what to say: an agent-theoretic approach to tutorial dialogue. In R-J.

Beun, M. Baker & M. Reiner(Eds.), Dialogue and Instruction. Springer-Verlag.
Bradshaw, J. & Young, R.M. (in press). Shared causal knowledge as a basis for communication between expert and knowledge acquisition system. In J. Boose, B. Gaines & M. Linster (Eds.), Proceedings of the 2nd European Workshop on Knowledge Acquisition. Bonn.
Buckingham-Shum, S. & Hammond, N. (in press). Delivering HCI modelling to designers: A framework, and case study of cognitive modelling. Interacting With Computers.
Driver, J. & Spence, C. (1994). Spatial synergies between auditory and visual attention. In C. Umilta & M. Moscovitch (Eds.), Attention and Performance XV.
DUFF, S.C. (1989). Reduction of action uncertainty in process control systems: The role of device knowledge. In E.D. Megaw (Ed.), Contemporary Ergonomics 1989 - Proceedings of the Ergonomics Society's 1989 Annual Conference (pp. 213-219). Reading, England. London: Taylor & Francis.
DUNCAN, J. (1981). Directing attention in the visual field. Perception & Psychophysics, 33, 20-28.
DUNCAN, J. (1984). Selective attention and the organization of visual information. Journal of Experimental Psychology: General, 113, 501-517.
DUNCAN, J. & Humphreys, G.W. (1989). Visual search and stimulus similarity. Psychological Review, 96, 433-458.
Fox, J., Cooper, R., Farringdon, J. & SHALLICE, T. (1992). Building computational models of cognition. In B. Silverman (Ed.), Proceedings of Workshop on Expert Judgement, Human Error and Intelligent Systems (10th European Conference on Artificial Intelligence, Vienna).
Frith, C. (1992). The Cognitive Neuropsychology of Schizophrenia. Hove: Lawrence Erlbaum Associates.
Frith, C.D. & Done, J. (1986). Routes to action in reaction time tasks. Psychological Research, 48, 169-177.
Frith, U. & Robson, J.E. Perceiving the language of films. Perception, 4, 97-103.
Funahashi, S., Bruce, C.J. & Goldman-Rakic, P.S. (1989). Mnemonic coding of visual space in the monkey's dorsolateral prefrontal cortex. Journal of Neurophysiology, 61, 331-349.
HOWES, A. (1992). Learning task-action mappings by exploration. Unpublished PhD Thesis, University of Lancaster.
HOWES, A. & Payne, S.J. (1990a). Display-based competence: Toward user models for menu-driven interfaces. International Journal of Man-Machine Studies, 33, 637-655.
HOWES, A. & Payne, S.J. (1990b). Semantic analysis during exploratory learning. In J. C. Chew & J. Whiteside (Eds), CHI'90: Proceedings of the Conference on Human Factors in Computing Systems (pp. 399-406). New York: ACM Press.
HOWES, A. & Payne, S. J. (1990c). Supporting exploratory learning. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds), Human-Computer Interaction - INTERACT'90 (pp. 881-885). Amsterdam: Elsevier Science Publishers.
Kinsbourne, M. (in press). Awareness of one's own body: A neuropsychological hypothesis. In J. Bermùdez, A.J. Marcel & N. Eilan (Eds.), The Body and the Self. Cambridge, Mass.: MIT Press, Bradford Books.
LAVIE, N. (1992). Perceptual load and physical distinctiveness as determinants of the locus of attentional selection. Unpublished dissertation (Hebrew).

McGurk, H. & Macdonald, J. (1976). Hearing lips and seeing voices. Nature, 264, 746-748.

Norman, D. A. (1981). Categorization of action slips. Psychological Review, 88, 1-15.

Reason, J. T. & Mycielska, K. (1982). Absent Minded? The Psychology of Mental Lapses and Everyday Errors. Englewood Cliffs, N.J.: Prentice-Hall.

Rizzolatti, G. & Gallese, V. (1988). Mechanisms and theories of spatial neglect. In F. Boller & J. Grafman (Eds.), Handbook of Neuropsychology (Vol. 1).

Robertson, L.C., & Lamb, M.R. (1991). Neuropsychological contributions to theories of part/whole organization. Cognitive Psychology, 23, 299-330.

Rubens, A.B. (1985). Caloric stimulation and unilateral visual neglect. Neurology, 35, 1019-1024.

Suchman, L. (1987). Plans and Situated Actions. Cambridge: Cambridge University Press.

SELLEN, A.J. & Norman, D.A. (1992). The psychology of slips. In B. J. Baars (Ed.), Experimental Slips and Human Error: Exploring the Architecture of Volition (pp. 317-339). New York: Plenum Press.

Shepard, R.N. & Cooper, L.A. (1982). Mental Images and their Transformations. Cambridge, Mass.: MIT Press, Bradford Books.

TEASDALE, J.D. & BARNARD, P.J. (1993). Affect, Cognition and Change. Hove: Lawrence Erlbaum Associates.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. Quarterly Journal of Experimental Psychology, 37A, 571-590.

Treisman, A. (1988). Features and objects: The Fourteenth Bartlett Memorial Lecture. Quarterly Journal of Experimental Psychology, 40A, 201-237.

Tsal, Y. & LAVIE, N. (1988). Attending to colour and shape: The special role of location in selective visual processing. Perception & Psychophysics, 44, 15-21.

Tsal, Y. & LAVIE, N. (1993). Location dominance in attending to color and shape. Journal of Experimental Psychology: Human Perception & Performance, 19, 131-139.

Tsal, Y., Meiran, N. & LAVIE, N. (1994). The role of attention in Illusory Conjunctions. Perception & Psychophysics, 55, 350-358.

Collaborations

Barnard

UK based

Eldridge - Rank Xerox Cambridge

Fowler - Clinical Psychology, Cambridge

Palmer - Clinical Psychology, Norwich

Harrison - Computer Science, York

Murray - Psychiatry, Cambridge

Outside UK

Jørgensen - Psychology, Copenhagen

Byerley, Böcker - SEL Pforzheim

Foa - Psychology, Pennsylvania

Linehan - Psychology, Seattle

Barnard, R Young (Esprit AMODEUS)

UK based

Harrison, Duke - Computer Science, York

Hammond, Buckingham-Shum - Psychology, York

MacLean, Bellotti - Rank Xerox, Cambridge

Duce - Rutherford Appleton Labs

Outside UK

Jørgensen, Aboulafia - Psychology, Copenhagen

Bernsen, Ramsay, May - Cognitive Science, Roskilde, Denmark

Nielsen - Business School, Copenhagen

Verjans - Expert Systems, Leuven

Löwgen, Sjøberg - Computer Science, Linkoping, Sweden

Coutaz, Nigay, Salber - LGI, Grenoble

Faconti, Paterno - CNR-CNUCE, Pisa

Darzentas, Spirou - Mathematics, University of the Aegean, Greece

Brown

UK based

Maycock - Transport Research Laboratory, Crowthorne

Outside UK

Michon - Traffic Science, Groningen

Duncan

UK based

Burgess - Psychology, London

Freer - MRIS, Cambridge

Hall - Medicinal Chemistry, Cambridge

Humphreys - Psychology, Birmingham

Johnson - Rehabilitation, Cambridge

Pickard - Neurosurgery, Cambridge

Robbins - Experimental Psychology, Cambridge

Outside UK

Bundesen - Psychology, Copenhagen

Desimone - NIMH, Bethesda

Orban - Neuroscience, Leuven

Seitz - Heinrich-Heine University, Dusseldorf

Shapiro - Psychology, Calgary

Goodrich

UK based

Harrison - Psychology, Charing Cross & Westminster Medical School, London

Henderson - Psychology, Hertfordshire

Driver - Psychology, Cambridge

Ashburn - Rehabilitation, Southampton

Groeger

UK based

Stove - Philips Research Labs

McMurran - Rover Cars

Parks - HUSAT, Loughborough

Allsop - UCL, London

Outside UK

Rothengatter - TRC, Groningen

Michon - NISCALE, Leiden

Verwey - TNO Institute for Perception, Netherlands

Bosser - Munchen

Cavallo - France

Esteve - CNRS-LAAS, France

Vallet - INRETS, France

de Santos - Braga, Portugal

Fuller - Dublin

Lynch - CARA Software, Dublin

Muskaug - Institute of Transport Economics, Norway

Andrew - Volvo, Sweden

Alm - VTI, Sweden

Houghton

UK based

Tipper - Psychology, Bangor

Lavie

UK based

Driver - Psychology, Cambridge

Outside UK

Tsal - Psychology, Tel-Aviv

Ivry - Psychology, Berkeley

Driver - Psychology, Cambridge

Marcel

UK based

Evans - Anaesthetics, John Radcliffe Hospital, Oxford

Garvie - Speech Therapy, Cambridge

Cole - Clinical Neurophysiology, Southampton

Eilan - King's College, Cambridge

Bermùdez, King's College, Cambridge

Campbell - New College, Oxford

Outside UK

Tegnèr - Neurology, Stockholm

Bisiach - Psychology, Padova

Berti - Psychology, Bologna

Ladavàs - Psychology, Bologna

Pizzamiglio - Psychology, Rome

Paillard - CNRS, Marseille

Sellen

UK based

Duthie - Papworth Hospital, Cambridge

Outside UK

Runciman, Webb, Williamson, Russell - Anaesthetics, Royal Adelaide Hospital

R Young

Abowd - Computer Science, Carnegie Mellon University

Lewis, Polson, Rieman - Cognitive Science, University of Colorado

Ritter - Psychology, Nottingham

MEMORY

Andrade 3.75, A Baddeley 4.0, Bekerian 5.0, Fulcher 0.92, G Houghton 2.0, Maylor 1.35, Murre 2.12, Nimmo-Smith 0.75, Norris 2.0, Page 0.84, Papagno 1.67, K Patterson 1.0, Sellen 0.73, Shanks 3.25, A Young 0.60, Wilson 1.0, Boden (ASO) 0.25, Dennett (HSO) 5.0, Evans (HSO) 0.83

Total Person Years: Scientists 31.0; Research Support 6..1

Abstract

Objectives

All human cognitive activity depends on our ability to store and retrieve information in memory. In this programme we attempt to understand both the basic processes of human memory and the interaction between memory and other cognitive processes. These goals are pursued by laboratory studies of both normal subjects and subjects with acquired memory disorders, and also by studying behaviour in more complex naturalistic settings.

Scientific progress and achievements over the past five years

The Working Memory model has become an influential framework for the study of memory. Extensive work on developing and extending the scope of the model has continued here at the APU. One of the more significant

discoveries stemming from research in the Working Memory framework has been that poor performance in repeating non-words correlates highly with delayed language development. This has led to the development of a non-word repetition test to predict problems in linguistic development. To complement the empirical research on working memory, we have developed computational models of serial recall which have so far proved successful in accounting for a wide range of data from serial recall paradigms. The Competitive Queueing model of serial ordering has been a major influence on other workers in the area.

More naturalistic studies of the manner in which memories change over time have led to the production of important practical guidelines for procedures such as medical interviews and evidential interviews with victims of crime.

In work on the cognitive effects of ageing, we have demonstrated declines that are not explained by traditional accounts based on single-factor models such as proportionate slowing. Disproportionate effects include forgetting rates in prospective memory tasks and retrieval blocks in naming tasks.

Progress has also been made in the study of neuropsychological disorders of memory. This work has shown that prosopagnosia (a deficit in recognising familiar faces following brain insult) can be due to a selective impairment of face memory rather than a more general perceptual deficit. Studies of the deterioration of semantic memory, in both generalised dementia of the Alzheimer's type and more focal "semantic" dementia, address questions about the neuroanatomical basis of semantic memory and also its functional organisation. For example, two detailed case studies of semantic dementia have documented progressive deterioration in specific semantic information with preserved higher-level superordinate knowledge, a pattern of data interpretable as reflecting a loss of specific features from a distributed network of knowledge.

Future plans for the next five years

Future research on memory will continue our present strategy of combining studies of both normal individuals and individuals with acquired memory disorders. Both laboratory studies and work in more naturalistic settings will emphasise the importance of memory as a component in the performance of other cognitive tasks. Much of the work, particularly in the areas of short-term memory and amnesia, will make increasing use of computational modelling and simulation to develop precise formal models in an attempt to gain a more detailed understanding of basic memory mechanisms.

Neuropsychological investigations will continue to be directed primarily towards the topics of semantic memory and face recognition. Patients with Alzheimer's disease will be examined to determine correlation between degree of semantic memory impairment and structural/functional abnormalities in brain regions assumed to be critical for semantic memory. Patients with semantic dementia will be studied to shed light on the distinction between episodic and semantic memory. Disorders of face recognition will focus on retrograde and anterograde components of face memory, and their relation to semantic memory for people.

Implications for improving health, health care and wealth creation

There is currently great concern over the reading abilities of young children. Our work on phonological memory and reading has led to the development of simple predictive tests which can help to identify those children likely to have difficulty in learning to read, and thereby help to optimise allocation of teaching resources.

Studies of memory under anaesthesia are part of the development of a new technique to monitor the depth of anaesthesia which may significantly minimise suffering during and following surgical procedures.
Effective interviewing procedures have an important role to play in ensuring the efficient operation of the criminal justice system. Our research in long-term memory has produced new guidelines for interviewing victims of crime.
Much of our work in memory has important implications for care of the aged. With an increasingly ageing population, it is vital that we have a better understanding of the cognitive limitations that accompany old age. The problems associated with Alzheimer's disease are an area of particular concern. Tests developed to assess the severity and course of the disease will be increasingly valuable as new methods of treatment develop.

WORKING MEMORY AND LONG-TERM MEMORY *(Andrade, Baddeley, Emslie, Papagno)*

A. Working Memory

Working memory refers to the temporary storage system assumed to be responsible for the maintenance of information necessary for complex skills such as learning, reasoning and comprehension. A tripartite model of working memory was proposed by Baddeley and Hitch some 20 years ago, and since that time has developed gradually. In recent years the model has had a major impact on this area of research, with invitations to Baddeley to give plenary addresses to the Cognitive Science Society and the European Neuroscience Society, and to publish review papers in a wide range of journals, including Science (3.12, 3.13, 3.14, 3.103). The model assumes three subsystems: the phonological loop holds and manipulates linguistic and auditory information; the visuo-spatial sketchpad is the visual counterpart of the phonological loop; both are assumed to be controlled by the central executive, a limited capacity attentional system (3.112).
A1. The Phonological Loop: The previous Progress Report described a patient with a deficit in this system who had specific problems in new phonological learning, such as that required to learn the vocabulary of a foreign language. While we have not had access to another single case as pure and dramatic as that in our original study, two milder cases of developmental deficit have allowed the original findings to be replicated (3.16, 3.27), while other single cases have elucidated the relationship between the phonological loop and comprehension (3.90), and between phonological processing and memory (3.28).
A major component of our recent work in this area has been designed to test the hypothesis that the phonological loop has evolved as a system for the acquisition of language. Much of this work has been carried out in collaboration with Susan Gathercole, who moved from the APU to the University of Lancaster, and subsequently to the University of Bristol. We showed that children with normal nonverbal intelligence, but delayed language development, had a marked deficit in the capacity to hear and repeat back an unfamiliar pseudoword (3.43). On the basis of this result, we developed the nonword repetition test, which we showed to be the best available predictor of vocabulary acquisition in children (3.44, 3.45, 3.50, 3.132). A longitudinal study using cross-lagged correlation indicated that it is good nonword repetition which leads to good vocabulary acquisition, rather than the reverse, in four-year-old children, although as children get older the pattern becomes more bi-directional, with existing vocabulary providing a model for remembering novel

(non)words (3.44). More detailed analysis of the test suggests two processes (3.49). One is based on items that resemble English words in structure, presumably reflecting the influence of prior vocabulary learning. The second is based on items that differ from English and hence presumably impose a greater load on phonological short-term storage. Performance on these latter items gives the best prediction of subsequent language development (3.48).

The relationship between nonword repetition and subsequent reading performance is more complex, with the association reaching an initial peak apparently associated with the stage of learning letter-to-sound correspondences (3.117). There appears to be a second peak several years later, although the amount of longitudinal data we have at this point is still limited. Phonological awareness, another predictor of reading, is correlated with nonword repetition; the two differ in that phonological awareness does not predict vocabulary acquisition, whereas both are associated with subsequent reading performance (3.46).

There has been some discussion as to whether the predictive power of the nonword repetition measure comes from its memory component, or from its capacity to reflect some alternative aspect of phonological development (3.47). It seems unlikely that models of either memory or phonological processing are sufficiently developed to separate these two interpretations of the developmental data. However, the observation that interfering with the operation of the phonological loop in normal adults leads to the impaired learning of novel vocabulary, while not affecting the capacity to associate pairs of meaningful words (3.70, 3.143), is consistent with our interpretation based on the memory component of nonword repetition. This supports a single interpretation of the developmental and adult data, whereas the alternative view would appear to require different hypotheses for children and adults.

We are currently exploring the hypothesis that the phonological loop is also involved in the acquisition of syntax, using a method in which normal subjects acquire artificial grammars under conditions that facilitate or interfere with the operation of the phonological loop. Future studies will also examine the role of phonological memory in the acquisition of syntax in both normal and specific language-impaired children, in a collaborative study involving Gathercole, Bishop and Baddeley.

A2. The Visuo-Spatial Sketchpad: Apart from collaborative studies with Logie in Aberdeen (3.59, 3.135), work on this component has focused principally on the studies of conscious awareness and the vividness of imagery described below.

A3. Working Memory and Conscious Awareness: A series of more theoretically oriented papers have speculated on the role of working memory in conscious awareness (3.106, 3.111). Stimulated by the work of Teasdale on the analysis of stimulus-independent intrusive thoughts (see Teasdale's section in the Cognition and Emotion Programme), we have carried out a series of experiments in which secondary tasks were used to study factors influencing the rated vividness of visual and auditory imagery. Baddeley and Andrade began with the hypothesis that a vivid visual image was one that was represented richly within the sketchpad, while an auditory image depended crucially upon the phonological loop. A series of studies indicated, however, that a major involvement of these two subsystems occurred only when the image concerned novel material that had to be maintained in memory using the systems in question. Disruption of these subsystems had little effect on the rated vividness of images for familiar sights or sounds presumably based on information retrieved from long-term memory. The data indicated that rated vividness was a function of the amount of information potentially available to the subject, regardless of whether this limit was set by the capacity of working memory or by the amount of prior knowledge. This hypothesis was tested directly in two studies; in one, duration of exposure of an unfamiliar pattern was used to vary the amount of information in STM; the image was rated as more vivid after a long than after a short exposure. In a second study, coloured pictures of British wild birds were shown, after which subjects rated the vividness of their recalled image of the pictures; vividness correlated highly with the subjects' prior ratings of knowledge of British birds.

A4. Awareness, Cognition and Anaesthesia: After general anaesthesia patients typically have no explicit memory for surgery. There is however evidence from indirect memory tests that some learning may occur despite anaesthesia (3.8). This learning may take place when the patient is completely unconscious or during moments of consciousness which are not detected and remedied by the anaesthetist (3.8). The latter situation arises from the widespread use of neuromuscular blockers. Although these drugs aid the surgeon by paralysing the patient, they hinder the anaesthetist by abolishing the reflexes which were traditionally used to indicate when the patient was gaining consciousness.

Jones and his team in the Cambridge University Department of Anaesthesia are developing a monitor of depth of anaesthesia which will show how unconscious a patient is even if he or she has been temporarily paralysed. Essentially, this monitor records the frequency of auditory stimulation which evokes the maximal response in the patient's EEG, known as the coherent frequency. This point of maximal excitation declines as the dose of anaesthetic increases, and increases with painful stimulation. Andrade and Baddeley collaborated with Jones et al. in a study designed to validate coherent frequency against other measures of brain function (3.11, 3.68). Volunteers were anaesthetised with incremental doses of isoflurane, at concentrations low enough to permit responding to target items on two cognitive tests (word classification and within-list recognition). Assessments of coherent frequency, memory (within-list recognition), and word classification performance at each dose revealed high correlations amongst these three measures, supporting the assumption that coherent frequency reflected awareness. On recovery from the anaesthetic, subjects were given a test of recognition for some of the stimulus items presented during anaesthesia. At 0.4% isoflurane, where subjects had still been able to respond to exemplars of categories and repeated words in the working memory task, they were subsequently unable to recognise the stimuli which had been presented at that dose. Hence, amnesia for surgery should not, in itself, be taken as evidence that a patient was unconscious during surgery. This work is continuing, with particular attention to the possibility of implicit or indirect measures of memory (see below).

A5. Working Memory and Executive Control: Serial recall of a sequence of spoken digits is impaired when an irrelevant word is interposed between each digit pair, the "sandwich effect". The effect is however far less than would be expected by a simple chaining model of serial order, and reflects the operation of an attentional preprocessing stage in immediate serial recall (3.26).

In random generation, the subject is required to produce a sequence of responses, making that sequence as unpredictable as possible. We have proposed that this is a task that loads heavily on the central executive since its essence is to avoid stereotyped and routine behaviour. It has proved successful as a secondary task, leading to substantial interference with skilled behaviours like chess playing which are assumed to place heavy demands on executive processes (3.12, 3.112). Baddeley, Emslie, Kolodny and Duncan attempted to analyse random generation as part of a U.S. Air Force-funded project on executive control. We showed first of all that the typical random generation task involving verbal production of letters or numbers could be replaced by one involving key-pressing. Subjects typically have 10 keys and attempt to produce 100 random responses. Analysis suggested that the essence of the task lies in the requirement to switch retrieval plans as frequently as possible, since staying with any one plan will tend to lead to increasingly stereotyped responding. Combining key-pressing with a range of other tasks indicated:

(1) That concurrent verbal digit span interfered with key-pressing: the greater the digit load, the lower the randomness of the output.

(2) Simple counting did not interfere, whereas tasks that are known to depend on the operation of the central executive, and that are typically impaired in patients with frontal lobe damage, cause substantial interference. These included semantic category generation and performance of a fluid intelligence test.

(3) We were able to test the retrieval-plan switching hypothesis by means of an apparently simple task that has low memory load but high switching cost. This involves giving the subject a number and letter (e.g. 7-E), and requiring continuation of this series (8-F, 9-G, 10-H, 11-I, etc.). This caused virtually as much interference as a concurrent intelligence test. We hope that this may allow the development of a new clinical test of one aspect of executive function.

A6. Dual-task Performance: One assumed function of the executive is to co-ordinate simultaneous performance of separate tasks. Earlier work in collaboration with colleagues in Milan demonstrated that patients suffering from Alzheimer's disease (AD) had great difficulty co-ordinating tasks simultaneously involving the visuo-spatial sketchpad and phonological loop, even when the level of the constituent tasks was adjusted so as to make young, elderly and AD subjects perform at an equivalent level under single-task conditions. Subsequent work showed a much more marked decline in dual- rather than single-task performance as the disease progressed, an effect that did not simply reflect task difficulty (3.20, 3.116). We went on to produce a logistically more convenient paper-and-pencil version of the initial task, and to investigate the performance of patients with frontal lobe damage on this new version. Impaired performance occurs in those patients who combine frontal lobe damage with behavioural disturbance, and as such appears to reflect a different component of the frontal syndrome from those measured by the more traditional tasks of verbal fluency and the Wisconsin Card Sorting task.

B. Long-Term Memory

B1. Implicit Learning and Memory: Memory can be tested either directly (explicitly) or indirectly (implicitly). Direct tests are those such as recall or recognition, in which one deliberately tries to remember something. Indirect tests, on the other hand, are tasks in which performance will be enhanced merely by previous experience with the stimulus items. For example, subjects have a higher probability of successfully completing the fragment m _ g _ it _ d _ if they have recently been shown the word magnitude, even when they do not remember seeing that word. Indirect tests have the potential to elicit evidence for memory in cases where the subject cannot explicitly recall information (3.158), although in other cases performance on indirect tests may reflect a mixture of both unconscious (implicit) and conscious (explicit) memory (3.99).

This area has formed the topic of PhD dissertations by Green and by Kolodny. Green's thesis demonstrated methodological problems with a standard paradigm (3.51), and went on to explore the interaction between the processes underlying direct and indirect measures of retrieval. She showed that direct or explicit retrieval can block access to implicitly available information, with the result that normal subjects may be handicapped relative to amnesic patients under certain conditions (3.149).

Kolodny's doctoral research was devoted to understanding the role of conscious and unconscious processes in several learning paradigms (3.150). Investigations of unconscious processing in the Serial Reaction Time learning task indicated that the learning may involve the acquisition of simple response bias as opposed to more complex knowledge structures, as had previously been assumed. A series of experiments examined the ability of subjects to classify paintings on the basis of artistic style. Using subjects with recollective ability that is either declining (elderly adults) or negligible (anterograde amnesic patients), these studies demonstrated that intentional retrieval may be essential for such tasks. In contrast, patients and normal controls performed at comparable levels in a task involving classification of dot patterns. It appears that conscious retrieval may not be essential for simple category learning but may play a crucial role with more complex material with a greater semantic content (3.56).

B2. Recency: While the recency effect in free recall has traditionally been associated with short-term memory, the working memory model has interpreted it in terms of the use of a particular retrieval strategy that may be applied to either long- or short-term memory. This view was supported by a study in which a patient suffering from impaired STM showed an absence of recency in an immediate memory paradigm but a long-term recency effect for the recall of anagram solutions (3.89). The task of remembering where you parked your car was shown by Pinto and Baddeley (3.39) to resemble the recency effect in immediate free recall in obeying the constant ratio rule, which relates the probability of recalling an item to a combination of elapsed delay and inter-item interval. A theoretical paper by Baddeley and Hitch suggested that the recency effect could be regarded as reflecting the application of an explicit retrieval strategy that takes advantage of implicit priming effects (3.23).

B3. Memory and Schizophrenia: A collaboration to investigate memory performance in schizophrenic patients has benefited from the move of our principal collaborator, McKenna, from the Department of Psychiatry at Leeds to Fulbourn Hospital, Cambridge. Subsequent work replicated our initial finding of a high prevalence of memory deficits in schizophrenic patients (3.67), and explored in more detail the nature of the deficit, demonstrating impaired episodic and semantic memory, together with comparatively preserved phonological working memory and implicit learning (3.87, 3.137). Subsequent work involving Wilkins has further investigated the semantic memory deficit (3.35), while Baddeley and colleagues from Fulbourn have begun to approach the understanding of delusional behaviour in terms of models of autobiographical memory (3.124).

The effects of schizophrenia on the various subsystems of working memory are currently being investigated in a study involving Baddeley and McKenna in Cambridge and Salamé from a new Strasbourg-based INSERM group studying schizophrenia.

C. Test Development

We have continued the process of developing clinical tests based on the cognitive psychology of memory. Investigation of semantic memory led to the SCOLP (Speed and Capacity of Language Processing) Test by Baddeley, Emslie and Nimmo-Smith (3.153). The test comprises two components, a measure of speed of sentence verification that is highly sensitive to both environmental stressors and brain damage, and a new estimate of premorbid verbal intelligence. Subjects are presented with a series of pairs, each containing one real word and one pseudoword, and are asked to "spot the word" in each pair (3.22). Since performance on this lexical decision task can be well preserved even in some types of acquired dyslexia, it seems likely to prove relatively robust to the effects of brain damage. Preliminary data based on Alzheimer's disease suggest that this is the case.

A new test of episodic memory has also been devised, the Doors and People Test (3.154). Separate subtests measure verbal recall and recognition (based on people's names), visual recall (based on copying and drawing from memory a series of shapes), and visual recognition in which the subject sees a series of coloured photographs of doors, and then has to recognise which of each set of four doors has been presented before. The test is completed by two delayed recall scores. It yields an overall episodic memory score which can be decomposed into separate visual and verbal, recall and recognition, learning and forgetting scores, all of which are standardised on the basis of a stratified population sample (3.154). The test has a wide range of applicability, from Alzheimer patients to young graduate students, and appears to be highly sensitive to the effects of normal ageing, schizophrenia and stroke. Finally, collaborative work with Dr Robin Morris of the Institute of Psychiatry has validated the sensitivity of the test to visual-verbal differences using a population of patients with left or right temporal lobectomy.

In collaboration with Susan Gathercole we have developed the nonword repetition test (described above) to a point at which it is likely to prove a valid and useful predictor of linguistic development, applicable down to the age of three (3.48). We propose to develop and standardise a new version of the test for use with all ages ranging from three-year-old children to adults.

The need for cognitive tests applicable to young children was emphasised by a recent invitation from the Partnership for Child Development to participate in a programme concerned with the possible cognitive consequences of parasitic infection in third world children (3.105). The programme was sponsored by the McDonnell Foundation, and aimed to call upon the expertise of developmental psychologists, cognitive psychologists and psychometricians. In a joint study carried out with Professor Grantham-McGregor and Dr Meeks Gardner of the University of the West Indies, we developed a series of new tests which were successfully used in a study on whipworm infection in Jamaica. Three new tests, one based on vocabulary acquisition, one on visual scanning and one on speed of sentence comprehension all proved usable under third world conditions, giving reliable data that correlated with measures of scholastic achievement (3.25).

D. Dissemination

The study of memory is one that evokes considerable intrinsic interest from the general public, and which has considerable potential for application. Dissemination to the general public has involved contributions to encyclopaedias, general scientific magazines and books of a general nature (3.104, 3.142, 3.163, 3.164, 3.167). In addition, Baddeley has attempted to link theoretical advances in the study of memory with its practical applications in the form of a text (3.1), and has completely revised Your Memory: A User's Guide, a book for the general reader (3.2).

We have also been concerned to ensure that recent developments in the psychology of memory are made available to colleagues in related disciplines (3.15, 3.108, 3.114, 3.117, 3.119, 3.143, 3.158). Perhaps the most notable recent example of our attempted dissemination is represented by a collaboration between Baddeley, Wilson and Watts to edit the Handbook of Memory Disorders (3.6). Over the last 10 to 15 years there have been great advances in our knowledge of memory disorders, together with a substantial start on the problem of how they should be assessed and treated. There is however, no single place in which the practising clinician can obtain up-to-date information on the state of the field. The handbook attempts to cover: the basic psychological and neurobiological background; an analysis of the major causes of memory deficit, both neuropsychological and neuropsychiatric; methods of assessment; and finally the current state of research on the management of memory problems. We were delighted that our colleagues in Europe and North America agreed to participate in the enterprise, and their contributions convince us that the book will be useful not only to a wide range of practitioners, but also to memory researchers.

FUTURE PROPOSALS

These are contained in a separate programme grant to be carried out after Baddeley's departure from the Applied Psychology Unit.

COMPUTATIONAL MODELLING OF SHORT-TERM MEMORY *(Baddeley, Fulcher, Houghton, Norris, Page)*

Introduction

Empirical studies of working memory are being complemented by a programme of computational work, designed to construct an explicit computational model of the processes in the Working Memory framework. Most of the effort has so far concentrated on modelling serial recall. Apart from their obvious implications for understanding memory and language processes, issues of serial order represent an intrinsically interesting computational problem of considerable generality.

A. Computational Modelling

In the first phase of the work, we have produced a simple connectionist model using both item-item and context-item associations in a feed-forward network. This model gives a good account of a range of basic short-term memory phenomena including primacy, recency, similarity effects and grouping. In addition to these basic phenomena, the model also simulates data on recall of lists containing a mixture of phonologically confusable and non-confusable items (Baddeley, 1968) which have proved beyond the scope of any other model in the literature (3.see Baddeley, Papagno and Norris, 3.121). Because the model simulates individual trials in a short-term memory experiment, it makes predictions about the detailed pattern of errors (transpositions, repetitions, etc.) as well as the overall serial position curve; these predictions are currently being evaluated.

Despite the architectural simplicity of the model, some aspects of its behaviour are difficult to understand. This is not simply because the model is connectionist, but because of the complexity of the interactions between its basic theoretical components. We are therefore supplementing the connectionist modelling with simple mathematical and statistical models, which help to isolate the individual components (e.g. context and item associations, item memory, phonological confusion) of the theory and to achieve a better understanding of their interactions.

The complexity of some of these interactions can be illustrated by one of the first results of this enterprise. We discovered that we could produce a classic serial position curve from a simple model incorporating the assumptions (i) that each successive list item is less strongly associated with a 'start-of-list' marker, and (ii) that there is a strong tendency for items not to be recalled twice (i.e. subjects can remember the items recalled). With noise in the recall process, this simple model generates both primacy and recency effects and gives a good account of the detailed pattern of transposition errors. Recency effects emerge partly because items that fail to be recalled in their correct position have a strong tendency to be recalled in immediately following positions, and partly because terminal items have no following items competing for recall. Recency is not dependent on any increase in strength or availability of list final items; indeed, simply increasing the strength of encoding of list-final items generally causes a decrease in recency. This mathematical model actually gives a better fit to the data than does our connectionist model and helps to identify key features which are essential properites of any effective model of serial recall.

We are currently using the knowledge gained by these simple statistical models to guide construction of further connectionist models and guide new empirical studies.

Concern with the problem of serial order is also evident in Houghton's work (Houghton, 1990). Houghton's competitive queuing model has been a major influence on other workers in the area. For example, competitive queuing formed the basis of a recent model of serial recall by Burgess and Hitch (1992).

FUTURE PROPOSALS

A. Computational Modelling

Future computational research will continue to concentrate on serial recall and chunking. Our immediate aim is to build on our success in producing a statistical/ mathematical model of serial recall and to incorporate the essential features of the mathematical model into a revised version of our connectionist model of memory.

One of our aims in this work has been to move the burden of explanation from considerations of 'architecture' to consideration of the way in which list items are represented in memory. Central to this is an investigation of the nature of the representations which support the coding of serial order. It seems impossible to account for serial recall simply by coding associations between list items (such accounts face particular problems in accounting for data from Baddeley, 1968). Associations must also be stored between items and 'context' (c.f. Schneider & Detweiler, 1987; Burgess & Hitch, 1992). However, the standard means of achieving this is to produce a contextual representation which evolves over list positions. This begs the question of how the context can be made to evolve in the same way at recall as it did at presentation. Our own work shows how serial recall could be supported largely by associations between items and context provided by the start of the list of items, thus avoiding the problems inherent in an evolving representation of context. Understanding the detailed nature of the representations supporting serial ordering is one of the fundamental issues in the explanation of a wide range of sequential behaviours and will be the major theoretical concern in future work on modelling short-term memory.

Currently our own models, as with TODAM, assume that subjects in a serial recall task are able to remember list items that they have already recalled so as to avoid repetitions. At present this is an assumption built into the model and the model does not have a memory for recalled items. We intend to add this component to the model and to examine subjects' memory for recalled items in experiments where lists include item repetitions. The behaviour of the model will be compared with a detailed analysis of the nature of errors and transpositions made by subjects.

We also intend to examine the relation between short- and long-term memory to study issues such as chunking and the role of representations in long-term memory in supporting short-term recall. For example, long-term representations may enhance short-term recall by supporting short-term memory representations, by reintegration (i.e. at retrieval), or by chunking. Given only a verbal expression, these alternative accounts are difficult to tease apart. Computational modelling can provide a clearer theoretical understanding of the implications of these different mechanisms.

In all of these cases, the computational modelling will be carried out in close association with experimental work. Deciding between alternative models often demands a fine grained analysis of error data. Serial position curves alone, which are typically all that is reported in the literature, are insufficient. This means that we have to collect our own data because, even when simulating well known phenomena, adequately detailed analyses of the data are rarely available.

CONNECTIONIST MODELS OF LONG-TERM FORGETTING AND AMNESIA *(Baddeley, Murre)*

Overview and cooperation

In the past two years, work was carried out on the development of several approaches to modelling long-term forgetting and amnesia. Most of these models are connectionist. One model is based on multi-dimensional scaling. Much of this work was carried out in cooperation with Baddeley. Work on long-term recovery of seemingly lost memories, such as a second language not used in many years, is undertaken in cooperation with Atkins. One of the models developed for amnesia has been generalised and is currently being applied in a more general theory of rehabilitation of brain injury, a project that is pursued jointly with Ian Robertson. For many of the technical aspects of neural network modelling, I have cooperated with Happel and Heemskerk at Leiden University.

A. Forgetting in LTM *(Murre, Baddeley)*

Neural networks do not generally show psychologically plausible forgetting curves. The most popular neural network paradigm, backpropagation, shows catastrophic forgetting: newly learned patterns lead to complete forgetting of existing memories. This effect was investigated and its main cause determined. One method of reducing the hidden-layer overlap is by occasional rehearsal (retraining) of earlier items APU 3185. This learning scheme is very similar to the learning method of expanding rehearsal, which is one of the most efficient learning strategies known.

Further exploration of forgetting in connectionist networks suggested that even very simple networks, without hidden layers are able to model human data. A series of simulations with a two-layer backpropagation network (only an input and an output layer) confirmed this intuition. The type of interference patterns obtained in these simulations mimic exactly those summarised in a classic paper on the role of similarity in interference in human long-term memory by Osgood (1949). The model was also successful in accounting for the effects of context-dependency of the type described by Godden and Baddeley (1975).

Another type of connectionist model was investigated that is more biologically plausible, without sacrificing psychological plausibility. These network models (Amari networks) use only positive activations and simple Hebbian learning. On the surface, learning in this model is completely different from that just described. Nevertheless, it can be shown that the basic effects of interference, described above, carry over to this class of models as well. That advantage of Amari models is that, compared to backpropagation models, both the structure and the learning method is in better agreement with current neuroanatomical models of the cerebral cortex.

An interesting aspect of our implementation of the Amari models is that a limited number of learned patterns (items) can become active at the same time. This is not possible in most other neural networks, where only a single pattern can be active at a given time. This co-activation of patterns is a plausible, and perhaps necessary, mechanism for the formation of item-item associations. The number of patterns that can be activated simultaneously is dependent on the total activation allowed. In this way, the total activation regulates something akin to a short-term memory buffer. There is not really a buffer in the networks because all patterns are distributed. The 'buffer' is a limit on the number of co-activated items that emerges through an overall limit on the activation level. When presented with a series of learned patterns under a new context, the first few items become attached more strongly to each other and to the context. This leads to the familiar primacy effect in free recall, simulated by activating the list context only. (This will then lead to recall of some of the associated items.) Since my primary aim was not to model working memory but amnesia, this aspect has not yet been further explored.

B. Amnesia

The Amari model described above was used to test several hypotheses about the temporal gradient in retrograde amnesia. Though the evidence for the preservation of old over recent memories is disputed, there seem to be several clear-cut cases where old memories were preserved better than recent memories. Simulations suggest that surviving older memories may have recruited additional nodes (neurons) and that these function as an additional 'support network'.

Rather than continuing with detailed simulations of specific effects in retrograde amnesia, we decided to leave the existing model aside for the moment and rather concentrate on the relation between anterograde amnesia

(AA) and retrograde amnesia (RA), as well as on various other forms of amnesia (including transient global amnesia, TGA). The literature suggests a complicated pattern of dissociations. The few existing computational models of amnesia all assume direct coupling of AA and RA, or they ignore the existence of RA altogether. This is a very unsatisfactory state of affairs. To accommodate the more complicated pattern of dissociations that are found, a blueprint for a new model was developed: the trace-link model. In its current form this is a global model comprising a trace system (simulated 'cortex'), link system (simulated 'anterior/medial temporal cortex'), and an modulator system (simulated 'hippocampus'). A new memory is formed by associating existing patterns in the trace system. The trace system is basically the Amari network described in the last paragraph, but in this model is thought to be many times larger and structured into different modules. Initially, the link system binds together the elements of a new memory. With time, associations will form within the trace system (supporting structures), and the memory becomes independent of the link-system. The modulator system is necessary to provide the plasticity to the connections in the link system. It causes increased learning in response to significant or novel events. The trace-link model can be shown to predict most of the dissociations between AA and RA. It can also deal with TGA, shrinkage, preservation of implicit memory under AA, and with temporal memory-gradients. It also gives a possible explanation for semantic dementia.

B1. Categorisation in Amnesia (Kolodny, Murre): When modelling forgetting, it important to study the underlying memory representations in the models. In particular, it is vital to know which types of categories can still be learned by amnesic patients. Kolodny has recently shown that amnesic patients are able to learn to categorise novel categories of dot patterns, but not artistic styles. This suggest that part of the processes involved in categorisation are based on explicit memory, whereas others may be involve implicit memory.

To get a clearer view on the processes underlying categorisation, existing models for the formation of categories were studied. This work builds on earlier work carried out at Leiden University (Murre, 1992). Simulations were carried out with an extension of Nosofsky's 'Generalised Context Model' for categorisation. This model is based on the formation of psychological spaces. All items in a category are remembered. Categorisation is carried out by comparing a new item to all items in a category. We developed an extended model which performed significantly better than Nosofsky's own model (using his data and taking into account the extra parameter available in the extended model). A connectionist implementation of this model has also been investigated.

C. Memory Repair

C1. Recovery in LTM: A model of forgetting and amnesia might allow certain predictions about the recovery of partially lost memories. Such recovery occurs in everyday life, when we visit France and have to speak French again after not having used the language for, say, ten years. It may also occur when recovering from brain damage whereby information and structure has been lost. As part of this project, we investigated recovery in the backpropagation model described under a). Relearning of part of a degraded set of words showed significant improvement in the performance of the rest of the set, even though that part of the set had not been relearned. A similar effect has been reported by Hinton for a different model (the Boltzmann machine), with a different type of disturbance (noise rather than interference), and with different patterns. In cooperation with Atkins we have been systematically exploring the extent and characteristics of this phenomenon in neural networks and in human subjects.

C2. Recovery from Brain Damage: In the brain, memories are under continuous threat of degradation by volatile neurochemical processes. It is likely that the brain invokes a dynamic strategy of continuous self-repair to restore lost information as soon as possible. In this hypothesised process, extensive use is being made of the redundancy of neural representations (as dense networks). Using the Amari network described above, several such strategies were tested based on continuing recruitment of neurons and the formation of new connections. Preliminary simulations and mathematical analysis show that memories are much more robust to lesions when even primitive self-repair processes are introduced. There is a critical lesion factor after which most memories will be beyond repair. Both mathematical analysis and simulations show that self-repair processes are very effective in prolonging the life of memories.

The idea of continuous repair of memories fits in well with Robertson's theories of rehabilitation, where cognitive functions consisting of many modules must be restored. Recent advances in neuroscience show that the brain is much more plastic than generally believed and that there are, therefore, good grounds for proposing more dynamic models of rehabilitation than those based on mere compensation strategies. We are currently working on a global connectionist model of rehabilitation which is described more fully in Robertson's section.

D. Technical Aspects of Neurosimulation

The practice of computer simulations with neural networks involves at least three technical areas: (1) optimisation of the architecture and parameters of a model, (2) development of appropriate simulation software (neurosimulators), and - possibly - (3) implementation in parallel hardware for neural networks. Because it is believed by many that neurocomputers will complement existing serial and parallel computers in the near future, these technical aspects continue to attract much interest by the engineering community. The technical aspects outlined below may, therefore, find application outside the realm of modelling and theory.

D1. Optimisation of Parameters and Architecture by Genetic Algorithms (with Happel, Leiden University): Genetic algorithms are search methods based on genetic evolution. We applied them to the practical task of finding the optimal parameter set and architecture for a model for handwritten-digit recognition. Prestructuring of a neural network in terms of broad connectivity patterns can be shown to greatly increase the learning speed and final performance (3.52).

D2. Development of Software for Neural Networks: Neurosimulators: Good software for simulation is indispensable. Modellers spend a large proportion of their time developing software. Earlier, in Leiden, several simulation environments were developed. One of these, MetaNet, makes extensive use of a graphical interface. This environment is extensive (30,000 lines of C-code) and can be used for many different neural network paradigms. It is, however, not yet fully functional. To increase the functionality of MetaNet by incorporating successful elements of other systems in academia, a large survey of existing neurosimulators was undertaken. Via repeated inquiries on e-mail, references to more than 100 systems were assembled, probably the most comprehensive database on neurosimulators. A review paper on 40 of these systems will appear in the 'Handbook of Brain Research and Neural Networks' (3.139).

D3. Implementation in Parallel Hardware: Neural networks are parallel distributed systems. Implementation of these models in parallel hardware can greatly speed up simulations. This is one of the reasons why the development of a parallel neurocomputer was undertaken in Leiden University (starting in 1989). This machine, the Brain Style Processor, has 400 processors, each of which implements the CALM algorithm developed by the author. This machine has recently been completed (3.53).

Design principles of very large neurocomputers have strong parallels with the design of the brain. For example, the problem of connecting millions of 'neurons' becomes an important issue. The connectivity problem also forms the basis of the model for amnesia outlined above. Implementation in existing parallel computers (transputer networks) was analysed from the perspective of various patterns of connectivity. It was proven that modular networks show better implementation characteristics than random neural networks.

FUTURE PROPOSALS

A. Forgetting in LTM

The forgetting model will be extended, so that it can better deal with the effects of context. Once this problem has been resolved, specific simulations will be carried out of the following effects: pro-active interference in the Brown-Peterson task, release from pro-active interference (by change in semantic category), and further aspects of retroactive interference. Preliminary analyses of the current, simple model have shown that certain aspects that have led to controversy in the 1970s (e.g., item-independence) can be tackled in a mathematical fashion. This line of research will be continued, taking into account inter-subject variability. Forgetting will also be investigated in the Amari network. If both the problem of context and interference in the Amari network are resolved, serial position curves will be generated in a simulated free-recall paradigm.

B. Amnesia

The present status of the model is that it characterises several findings in amnesia in a global manner. The next stage is to develop a more detailed model. The final aim is to integrate the global model with the Amari network, in this way arriving at a model that is capable of explaining both normal forgetting and (when lesioned) pathological forgetting (amnesia). The studies described earlier will enable rapid development of such a model. Further refinements must subsequently be carried out, based on specific patient data. A specific topic to be explored is preserved implicit memory under retrograde amnesia. Because few patient data are available, the model might be used to yield specific predictions which can then be tested on patients.

B1. Categorisation in Amnesia: Integration of the categorisation model with the amnesia model will be undertaken. The amnesia model has been designed with this purpose in mind, among others. A specific task is to model Kolodny's data on categorisation. This exercise will shed more light on the question of what processes (implicit or explicit memory) are involved in categorisation of probabilistic stimuli. Further psychological experiments with amnesic patients will be necessary to be able to develop a fully articulated theory on this issue.

C. Memory Repair

C1. Recovery in LTM: Recovery of seemingly lost memories will be pursued further in cooperation with Atkins. Several experiments will be carried out to establish under what conditions the phenomenon occurs. In addition, single-case studies will be carried out with extensive - but controlled -exposure to a 'forgotten' language, such as Chinese learned over ten years ago and not used since then. The hypothesis is that partial exposure will result in improved performance on the rest of the language, to which the subject has not yet been exposed. This plausible hypothesis still remains to be validated under controlled circumstances. If demonstrated, the corresponding effect in neural networks with hidden representations will be explored in backpropagation and Boltzmann machine models.

D. Technical Aspects of Neurosimulation

D1. Optimisation of Parameters and Architecture by Genetic Algorithms: This line of research will not be pursued further. The software and methods developed so far are adequate to act as tools in further modelling research.

D2. Development of Software for Neural Networks: Neurosimulators: MetaNet will be developed into a fully functional system. Several partial systems will be constructed first, to test the feasibility of the solutions. The final aim will be to arrive at a flexible system that is first of all of use to modellers in psychology.

D3. Implementation in Parallel Hardware: We will continue to study the connectivity problem in neurocomputers and in the brain, in cooperation with Heemskerk in Leiden. At present, a design for a very-large neurocomputer based on a fractal architecture is being developed. This work builds directly on previous work on the Brain Style Processor, which has a modular architecture. We will compare the hypothetical performance of a variety of neural network architectures on a range of processor topologies (including fractal, modular, and grid) using both analysis and simulation.

CAUSALITY, CLASSIFICATION AND IMPLICIT LEARNING *(Shanks)*

A. Judgement of Causality

Shanks has been exploring the processes that control the perception and judgement of causality in humans (3.73, 3.76, 3.78, 3.81, 3.82, 3.131). Studies have shown that perceived causality in a Michottean collision task can be dissociated from cognitive judgements of causality (3.73). It has been argued, on the basis of correspondences between conditioning and causal judgement (3.76, 3.81, 3.131), that conditioning is a mechanism that has evolved in order to pick out causal relationships in the world.

A debate has taken place on the extent to which causality judgements are normatively accurate (3.82), and experiments have been conducted (3.82) which question the assumption of normativity. For instance, judgements are strongly affected by the order in which trials are presented.

B. Classification

Shanks has carried out a number of empirical studies of human category learning (3.145, 3.77, 3.79, 3.80, 3.174) aimed at testing connectionist, rule-based, and exemplar models. These tests have successfully discriminated between the three classes of theories, with connectionist models being generally supported. Theoretical work on the topic of category learning (3.151) started from the observation that models of learning based on the backpropagation learning algorithm and architecture suffer from two major flaws: (i) they cannot account for the effects of selective attention on learning, and (ii) they suffer from catastrophic forgetting. An example of the former is the finding that it is easier to classify stimuli if only one dimension is relevant to the classification than if two dimensions are relevant. Evidence of catastrophic interference comes from demonstrations that information is completely eradicated in backpropagation networks when later, partially-overlapping information is encoded. Although humans do of course show forgetting in such circumstances, they are affected to nothing like this catastrophic degree.

As an alternative to backpropagation, Shanks (3.151) developed a new model called the consequential region model which avoids these problems and generates excellent fits to published category learning data. In the model, stimuli are represented by the activation of large numbers of hidden units whose receptive fields correspond to hypotheses concerning the size and shape of the category in the input space. A process of selection, via the delta rule, picks out those hidden units which are most predictive of category membership. The results illustrate how an associative network can show appropriate sensitivity to inter-item similarities among training exemplars as an emergent property of its scheme for representing stimuli.

C. Implicit Learning

Another topic that has been of major interest to students of associative learning is the question of whether learning can occur implicitly. The notion that there exist independent explicit and implicit learning systems combines two further distinctions, (i) between learning that takes place with, versus without, concurrent awareness, and (ii) between learning that involves the encoding of instances (or fragments) versus the induction of abstract rules or hypotheses. Implicit learning is assumed to involve unconscious rule learning (3.173).

Experimental work has been undertaken (3.84, 3.51, 3.85) which questions some published claims, from reaction time and system control studies, concerning implicit learning. For instance, we (3.51) were unable to replicate some of Broadbent's evidence for implicit learning.

In an extensive review, Shanks (3.152, 3.85) examined the evidence for implicit learning from studies of subliminal perception, conditioning, artificial grammar learning, instrumental learning, and reaction times in sequence learning, and concluded that unconscious learning has not been satisfactorily established in any of these areas. The assumption that learning in some of these tasks (e.g., artificial grammar learning) is predominantly based on rule abstraction is also questionable. When subjects cannot report the "implicitly learned" rules that govern stimulus selection, this is often because their knowledge consists of instances of fragments of the training stimuli rather than rules. In contrast to the distinction between conscious and unconscious learning, the distinction between instance and rule learning is a sound and meaningful way of taxonomizing human learning. Various computational models of these two forms of learning have been considered.

REMEMBERING SPECIFIC EVENTS *(Bekerian)*

Introduction: Long-Term Memory for Specific Events

Memory represents one of the most essential cognitive abilities for normal human functioning. We constantly rely on our ability to refer to the past and to use previously acquired information. Our research has attempted to provide some insight into this ability. The research is unified by a concern for naturalistic situations where remembering -- what is claimed to have happened in the past -- determines the fate of lives. In the most dramatic case, for example, we examine how people remember physical and sexual abuse in evidential interviews.

The research relies on data from laboratory experiments and observational studies. Such converging methodologies are not only essential from the standpoint of application of the research. Importantly, the use of different methodologies has allowed us to maintain the integrity of theoretical arguments when they are applicable, and extend and/or qualify such arguments in the face of specific naturalistic contexts.

The application of the research has been particularly successful, especially with regard to issues of public health. These will be discussed more fully below. We merely note here that thus far the application of the research has ranged from the development of mnemonic aids through advancements in information technology, the training and assessment of professionals responsible for the interviewing of alleged victims of child abuse, to the effectiveness and dangers of therapeutic intervention for victims of violent crimes.

The research retains notable objectivity in discussing otherwise highly sensitive and politically dynamic issues, for example assessments of Home Office guidelines for the video interviewing of child witnesses. This has resulted in the Bekerian being approached to overview highly productive, and highly controversial areas of applied memory research, for example eyewitness identification, and offender profiling. Apart from the main research interests, Bekerian also serves as an advisor on cases of appeal (for example, JUSTICE) as well as general Police enquiries. Because of the obvious applicability and importance of our research to issues of public concern, we have also been involved in the recording and production of BBC educational television, and national television and radio programmes. In each case, Bekerian provided expert opinion on applied memory issues.

The general themes that form the theoretical basis for the research will be discussed under three major topic headings: a) the malleability of memory b) individual variability in memory, and c) the effects of remembering environment.

A. The Malleability of Memory *(Bekerian, Shaw, McCubbin)*

Remembering changes over time: old details drop out; new details are included. The stability, and instability of memory is of great theoretical debate. For example, stability in the information recalled is assumed to indicate when an account is based on a real event, as opposed to confabulated memory. Such considerations also form the basis for the application of cognitive theories of memory in many criminal cases. For example, any inconsistencies in a witness' account may cause grounds for disbelief, unless these changes can be assumed to be part of "normal" remembering. Knowing when, why and how, remembering changes are important.

Our research has focused on why memory improves over time. We have looked specifically at the phenomenon of hypermnesia, where a person remembers more new information than s/he forgets (3.86). The research has involved a series of experiments that have used interference paradigms, looking at the effects of interpolated activity on memory for concrete word pairs. The work is the first to use the interference paradigm to investigate hypermnesia, so the results are of particular importance. One of the major explanations for hypermnesia is that imagery at the time of learning is responsible for hypermnesia. Our experiments have shown that although imagery at encoding is a necessary condition for hypermnesia (abstract words do not show memory improvement), it is not a sufficient one. Rather, the results suggest that the distinctiveness of the information seem more important. For example, when interpolated material is processed in a manner similar to that of the original material, no hypermnesia occurs, regardless of whether the interpolated materials are processed at "deep" levels (interactive imagery) or "shallow" (separate imagery) levels.

Other work in progress has extended our interest in hypermnesia and the interference paradigm, looking at the effects of emotional arousal on memory improvement (3.101). There is some considerable controversy over the effects of arousal on memory. Some argue that arousal interferes with processing capacity, thereby reducing the "strength" and type of information originally encoded; others argue that arousal can enhance the processing and subsequent retention of information over time. Our findings suggest that negative arousal interrupts hypermnesia, but only when it occurs during interpolated trials, not when it occurs prior to original learning, suggesting, as before, the importance of the interpolated activity. These findings are important for discussions of inconsistencies in real victim's accounts of trauma. For example, if it is the case that hypermnesia can occur for events initially experienced with great trauma, certain inconsistencies in a victim's account may not be grounds for great concern.

B. Individual Variability in Memory *(Bekerian, Barnard, Eldridge, MacLeod, Williams)*

Research in this area has highlighted the importance of individual variability in the way that information is remembered, and in the manner in which information might be represented (3.42, 3.60). One argument is that individuals differ significantly in terms of the level and content of their representation of their daily lives. A novel deviation of the research is that it has focused on time periods of life that have received little theoretical attention (3.42). For example, the research examines schemas for a person's working day, using both free and cued recall paradigms. Schemas are generally discussed in terms of very global structures, such as life-time periods, or single events, like going to the dentist's. In contrast, the schema for a "working day" is at a more intermediate level: many single events make up a "day". The findings suggest that the degree of elaboration and content of an individual's schema can predict memory performance, and forgetting (3.42). For example, people with more elaborate schemas retain more information about typical activities than people with less elaborated schemas. These represent relatively novel discussions of autobiographical memory phenomena, which typically do not consider individual differences in this manner.

Current work is examining the fluctuations in an individual's schemas and the degree of elaboration of such representations (Bekerian, Eldridge, Barnard). The hypothesis is that everyday schemas undergo constant updating and modification. Consequently, the pattern of memory, even for daily events, may fail to be consistent over time. Importantly, similar arguments concerning the unstable nature of representations have been made in the context of semantic memory research; but, not within episodic memory research.

The practical applications of this work have been through the MRC's involvement with Rank Xerox EUROPARC, on the development of automatic mnemonic aids for the work environment. As the practical demands placed upon memory in the workplace increase, the potential uses of information technology to support memory become more important. The MRC have been responsible for providing normative information about what people remember of their working life illustrating in the first instance the nature of memory problems that people might have. For example, we have shown that people's memory for institutional talks (such as seminars, or formal expert talks) is appalling after only a week (sometimes at chance), and that the reinstatement of cues, like overhead transparencies used by the speaker, fail to improve performance. These data suggest that the potential application of automatic mnemonic aids may have to be restricted to "simpler" memory problems, such as object location (e.g., finding the folder in which you saved a particular electronic file).

C. Effects of the Remembering Environment *(Bekerian, Dennett, Dritschel, Toplis, Wing)*

C1. Empirical Studies: Over time, people may have to remember the same event across different circumstances, such as recounting a first date to one's mother and, then, to one's best friend. These circumstances, which we term the 'remembering environment", have been of particular interest, in that the remembering environment is, potentially, manipulable in real world situations. One of our concerns has been the predominance in experimental investigations of what has come to be called episodic remembering (3.130): the person is requested to recount a specific event that occurred in the past, and is intentionally engaging in the act of remembering. This type of remembering parallels important characteristics of many real world situations; for example, in an evidential interview, the interviewer requests the witness to engage in episodic remembering. However, there are other conditions under which people remember events. For example spontaneous remindings that occur in the course of a conversation seem more like the result of some "priming" mechanism, rather than any intention to remember. Similarly, phenomena such as flashbacks, where there is an unrequested, unintentional and unwanted remembering of an event are also outside the scope of most theories of autobiographical memory.

The research has identified the effects of subtle differences in the types of remembering environments. For example, a simple manipulation was introduced whereby the person was asked either to speak, or write, the account (3.32). The findings showed that speakers produced more correct information than writers. We are currently pursuing the possibility that writers suffer interference of Working Memory processes, due to the demands placed on them by the writing task itself. For example, writers may be at a disadvantage, since the visuo-spatial scratchpad is otherwise occupied by the task of writing. Imagery instructions, which encourage the formation of a visual image prior to output, would be expected to have an effect on writers, but perhaps not speakers, if this is correct. Preliminary analyses have revealed that imagery instructions do effect speakers, both in terms of correct as well as incorrect information that is recalled (3.129). We have already considered the serious implications these results have for real interview techniques that rely on imagery as a technique to reinstate context (3.33). For example, encouragement to image may result in the person falsely "remembering", with confidence, details that were never present.

We have also been concerned with the theoretical debate over whether accounts based on real memories differ quantitatively and qualitatively from those based on fictionalised memories. The practical implications of this debate are immense. If it were true that certain features in an account can distinguish real from confabulated memories, the application would be seen across the legal/civil domain, ranging from witness reports to accusations of 'recovered' memories of sexual abuse.

Our review of the evidence has suggested that certain criteria seem to be uniformly regarded as indices of "real" memories. These criteria include the presence of perceptual detail, the spontaneous nature of the account, and an unstructured narrative style. We have argued that the remembering environment will influence the presence of these criteria independently of the "truthfulness" of the account. For example, we have reasoned that frequently experienced events are likely to be reported first in a schematised fashion, lacking extensive perceptual detail. Unless directed otherwise, the person may fail to provide a specific episode; alternatively, the person may be unable to recount a specific episode without some prompting, e.g., tell me about an event, x, where something unusual or surprising happened. Our work in this area has been extended directly to observations of real allegations of abuse, which will be discussed below.

Other work has examined experimentally what determines whether a person remembers a specific incident in response to a question, or whether they remember some "schematic" memory (3.95). We have used a dual task paradigm, with one task being question-answering, and the other, tapping to a rhythmic beat. The tapping task requires some executive capacity, so puts a cognitive load on the person when performed with another task (relative to the single task conditions). The questions were everyday, common routines, increasing in novelty (i.e., deviation in the script). For example, a common routine question is "How do you brush your teeth with a toothbrush?" The least deviant question is "How do you brush you teeth if you have to use your finger?" The most deviant question is "How do you brush your teeth if you only have a stone?" We have shown that schematic memories are more likely to be remembered when the person is engaged in two tasks (i.e., when the cognitive "load" is greater), for common and least deviant questions. This suggests that it is easier to remember schematic memories particularly when under some stress. Further, we have shown that specific autobiographical memories are infrequently remembered, and this seems to be related to whether they match the question fairly precisely (e.g., I once had to brush my teeth with my finger), or, alternatively, whether they have been recently experienced (e.g., experienced shortly before the testing session). These findings provide empirical support for our argument about the effects of frequently experienced events and the schematic nature of memory. In addition they provide new data on the quality of autobiographical memory under cognitively demanding conditions.

C2. Naturalistic Observations: The theoretical arguments emerging from the empirical work have been developed in parallel with detailed analyses of therapeutic interviews and evidential interviews with real victims of serious crimes (3.125, 3.126, 3.127, 3.128, 3.146, 3.147, 3.168, 3.169), in the main, alleged victims of child abuse. There has been extensive collaboration between Bekerian/Dennett and the Statutory and Caring Agencies responsible for the interviewing of such victims. These Agencies have provided Bekerian/Dennett with video-tapes, transcripts and statements of real interviews, as well as case-relevant details.

The implications of this research for the assessment of interviewing skills should not be underestimated. Ineffective interviewing of victims of trauma or serious crimes is an issue of general public and social concern. It is costly, in terms of man-hours, in terms of expenditure of otherwise limited training budgets, and in terms of human discomfort. For example, of all cases of child abuse passed to the Crown Prosecution Service (CPS) by the police (approximately 250 in the region a year), only seven percent are considered for prosecution (about 18 cases). Of those 18 cases, only one is likely to sustain a successful prosecution. The CPS cite poor interviewing techniques as one of the primary reasons for this surprising discrepancy.

Procedures for analysing both the interviewer's and the victim's behaviour have been an essential component of this work. The analyses address both practical and theoretical issues. For example, we have devised a means of depicting interviewer behaviour in a way that can distinguish evidential style interviewing from therapeutic style interviewing (3.146, 3.147, 3.128). This distinction is critical in practice. Home Office guidelines stipulate against the use of therapeutic interviewing for alleged child abuse victims. Theoretically, the distinction between styles of interviewing is important, as the distinction forms the basis for arguments in the "repressed memory syndrome" debate. For example, therapeutic style interviews, because of their emphasis on emotional interpretation, might be expected to yield highly reconstructed and embellished accounts, rather than highly veridical ones. Because the data-base is derived from actual interviews, the work has the advantage of directly linking theory with practice.

We have focused on factors that are likely to influence episodic remembering of child abuse (3.125). In particular, we have examined the evidence regarding the effectiveness of different interview techniques, particularly those which claim to enhance memory without simultaneously increasing incorrect recall (3.33, 3.126). For example, we have argued that mnemonic techniques should be introduced later, rather than earlier in repeated interviews, simply because such techniques are likely to introduce errors into the account as well as enhancing correct recall (3.33). Additionally, we have identified potential advantages and disadvantages of using mnemonic techniques with specific subject populations and event scenarios (3.33, 3.125, 3.126, 3.127, 3.129). For example, encouraging the use of imagery with a suggestible witness (e.g., a young child of four) is considered a dangerous tactic, given it may promote incorrect details being recalled.

The development of procedures for analysing interviewer/victim behaviour is a critical achievement (see 3.42, 3.128). No other procedures for analysing memory in evidential interviews are available within the published literature, rendering the work unique in its status (3.128). Although these were developed in the context of our collaborative work on child abuse, the application to other dyadic conversations is straightforward, and serves as the grounds for future research into therapeutic intervention.

Our procedures and analyses of interviews have already been incorporated into interviewer training programmes on violent/traumatic crimes that are conducted by the County Statutory and Caring Agencies (3.146, 3.147). Reactions from these Agencies have been unreservedly favourable, as the procedures have proven successful in identifying areas of strengths and weaknesses in an interviewer's skill. The work is now being considered by Regional Health Authority, and this future work will be discussed

The issue of validation has been particularly important, for obvious reasons. Thus far, we have considered the effectiveness of our input to training in the following way. There are certain types of interviewing that both cognitive theory, and the law, say an interviewer shouldn't use: these include leading questions, closed questions, questions based on emotional interpretation, coercive questions, sudden changes in topic, and so on. People who interview in that way are considered "poor". Part of our assessment has been to identify these more "undesirable" styles, and compare the styles of interviewers who either have or have not been on formal courses, in order to determine whether formal training has any effects.

The success of the work has led to extensive involvement with and membership on national and Home Office working parties that are responsible for the review and recommendation of working practices/guidelines for the interviewing of victims of serious crimes (Association of Chief Police Officers, Personnel and Training Committee, Working Party on Investigative Interviewing; Association of Chief Police Officers, Steering Committee on Offender Profiling; Home Office Video Guidelines for the Interviewing of Child Witnesses). Additionally, Bekerian is a member of the BPS Working Party for the Recovered Memory Syndrome, which will provide a report regarding the nature of the false memory syndrome in September, 1994. Most recently, Bekerian has been asked to provide a peer commentary over the debates of recovered/false memories.

We have established collaborative links with Dr. J. Jackson and the Netherlands Institute for the Study of Criminality and Law Enforcement (NISCALE) concerning interview techniques of witnesses/suspects. Prof. U. Undeutsch (University of Koln, Koln, Germany) has also been an important collaborator in research concerning the assessments of truth in statements of alleged child abuse victims (see 3.125, 3.127), providing us with statements of evidential interviews with alleged victims.

Work in progress is involved in the systematic review of current practices in the investigation of serial crimes, focusing on interview techniques that are used in the United States, Great Britain, the Continent and Australia.

FUTURE PROPOSALS

A. The Malleability of Memory

Changes in "Self": People have a notion of a "self" which represents their own personal set of beliefs, values and attitudes. Autobiographical memory largely relies on this notion, as without a "self" the concept of autobiographical memory becomes somewhat curious (3.130; see Barnard & Teasdale, 1991; Bermùdez, Marcel & Eilan, in press). Our particular concern here is how changes in the "self" effect what is remembered of a highly traumatic event. Specifically, we define changes in "self" as remission from Post-Traumatic Stress Disorder (PTSD).

The project uses clinical populations who are victims of rape suffering from Post-Traumatic Stress Disorder (PTSD) and are referred for therapeutic treatment. Therapeutic sessions require the client to remember the event as part of the therapeutic intervention technique. Changes in emotional reactions are monitored through the use of anxiety ratings. Discourse analyses of clients' memories will be based on procedures that have already been proven successful in similar contexts (see 3.128). Analyses will identify quantitative changes in memory, and qualitative changes in memory, e.g., changes in metaphor, personalised nature of the information.

Control (i.e., non-clinical) populations will be asked to remember significant life events across repeated sessions. Personal ratings of the significance, emotional valence of and emotional reaction to the event will be taken. These data will provide some indication of the spontaneous changes that occur in remembering. Given that the therapeutic intervention is very non-directive, the comparison with control data is somewhat less problematic.

The findings will be of importance to theories of self and autobiographical memory, illustrating the extent and nature of the influence that changes in self have on how people remember events from their past. Additionally, the findings will be useful in informing us about the "normal" changes that might be expected to occur in memory of trauma, extending our interest in phenomena such as hypermnesia.

The work also has implications for more general discussions of the effects of therapeutic intervention on memory, for example, the "false memory syndrome", where therapeutic intervention is accused of implanting false memories of abuse. For example, recent work suggests that memories based on real events are largely invariant, with only "false" memories showing the sudden recovery of details. Given the data collected on PTSD victims will be based on real events, any changes in remembering will be particularly informative towards this debate.

The work will be done in collaboration with Prof. E. Foa (Rape Crisis Center, Philadelphia), who will provide necessary transcripts of therapeutic interviews. (It is likely that T. Dalgleish (MRC APU) will be a potential collaborator, given his expertise in PTSD).

B. Individual Variability in Memory

The role of language in autobiographical remembering. Our previous discussions of childhood remembering (3.125, 3.127, 3.168, 3.169) have suggested that verbal fluency will determine whether certain mnemonic techniques are appropriate. This proposed work intends to examine the relationship between normal language development, and the emergence of autobiographical memory. There is currently a question whether fluency in language is a necessary condition for the normal development of autobiographical memory in children. The proposed work intends to examine this possibility through investigations with language impaired individuals. In particular, it is hypothesised that language impaired individuals should show marked deficits in quantitative and qualitative characteristics of autobiographical memory that are normal for the age group. Initially, the work will adopt a cueing paradigm to look at autobiographical remembering, in that this paradigm has been widely used with both adult and child populations. The work will be conducted in collaboration with Dorothy Bishop, who has access to language impaired and unimpaired children.

C. Effects of the Remembering Environment

C1 The Task of Autobiographical Remembering: What is remembered will depend upon how one queries memory, i.e., the remembering environment. Such concerns are particularly important within applied contexts, since it is critical to determine which conditions are likely to produce changes, and whether the changes are in a favourable or unfavourable direction. The project explores the possibility that as the task of remembering changes (for example, the reasons for remembering), the content of the account and its structure will vary accordingly. The suggestion that memory can vary so dramatically, depending on the task, is one which has great potential implication, both for theory as well as in the applied setting. For example, if certain remembering tasks can be found to improve memory performance, such manipulations would be easy to administer in the applied situation.

Methodologies of repeated observations and variations in the narrative demands of the task (e.g., story-telling vs. descriptive accounts) will serve as the basis for empirical work, with naturalistic or observational studies supporting the experimental paradigms. It is expected that different narrative demands will yield different memories, both in content (for example, more interpretative information) and format (for example, more personalised utterances, such as the use of "I").

Another application of these findings is with regards to the differences between the therapeutic context and other interview contexts, a concern which has already formed the basis for much of our earlier work.

Therapeutic interviewing is often considered to be different from other types of interviewing because of its explicit emphasis on personal interpretation. However, an equally obvious characteristic of the therapeutic interview is that it focuses on a narrative styles of remembering, much more so than other interviews . Therefore, any effects of narrative instructions that we find under laboratory conditions will identify the consequences of adopting different remembering tasks, per se, regardless of the particular explicit nature of the interview styles.

C2. Disadvantages of Mnemonic Techniques: Remembering typically includes information that is wrong, e.g., a yellow hat is remembered as being red. The person "remembers" incorrect information, and misleads him/herself into believing that these errors are "true". The proposed research extends theoretical arguments set forward in an earlier review (3.33) and examines the consequences of the use of one particular memory enhancing technique on spontaneously generated errors. This technique, the Cognitive Interview technique (CI), is widely used in the context of evidential interviews (i.e., with victims/witnesses/suspects of crimes), therapeutic interviews, accident investigations, and in public health care studies (e.g., children's dietary habits).

Two general questions will be addressed, across a series of experiments: one, the consequences of CI with respect to qualitative characteristics of memory; second, changes occurring in memory over time. Assessments of qualitative characteristics of memory will be investigated through the use of memory attributions, or states of awareness, for example, whether a person distinctly remembers encountering the information or whether they merely know they encountered it. Generally, "remember" states are associated with higher confidence, and, in turn, are more likely to be believed as "true", when compared with "know" states. Mature and young adults, as well as adolescent and child populations will be used, since there is little evidence concerning the developmental changes that occur in the ability to make memory attributions. Delays in recall will determine whether extended intervals render discriminations more difficult. This work will be in collaboration with Prof. B. Clifford and R. Toplis (Psychology Dept., University of East London) who will provide adolescent and child populations.

It is hypothesised that CI -- relative to "standard" interview procedures -- will result in the person being biased to "remember" incorrect information and being highly confidence in this information. These effect should be more pronounced with longer delays between recall attempts. These predictions are based on assumptions about how people decide they are "remembering". For example, mental context reinstatement -- the most powerful mnemonic used by CI -- requires that the individual form a mental image of the physical environment prior to recall. With encouragement to form highly detailed contexts, the person is likely to attribute an error as being "remembered" by virtue of the extensive context under which it was produced.

Given that CI is used so extensively, any new data will have certain practical implications. For example, should CI promote more confident errors, this would have severe consequences for the use of the technique in real-world investigations. It is well established that more confident witnesses are more credible. As such, more confident errors are likely to be believed as true. This work will be in collaboration with Prof. B. Clifford and R. Toplis (Psychology Dept., University of East London) who will provide adolescent and child populations.

Most recently, the National Opinion Research Group Ltd. has solicited Bekerian's expert opinion on the use of CI for their training of market research interviewers. It is anticipated that Bekerian will be an advisor for NOP, helping them to develop training programmes, and identifying the applications of cognitive techniques like CI for market research.

C3. Naturalistic Observations of Memory: The proposed work continues the analyses of real interviews of victims of serious crimes, under both evidential and therapeutic settings (see 3.146, 3.147). Procedures used for analyses have already been developed and have provided essential information to the Statutory and Caring Agencies (i.e., County Police, Social Services, NSPCC) regarding interview skills (see APU 3.128). This work will be critical in the appraisal of current interviewing skills evaluated through specialised courses currently on offer by these Agencies, and will also determine the successfulness of training procedures in promoting better practice.. As a direct consequence of the work that has already been completed for the Agencies, the North West Anglia Health Authority is encouraging Bekerian to submit a proposal which would provide analyses of evidential interviews with alleged child abuse victims across the region. In particular, the Health Authority is concerned with the quality of interviewing currently being achieved by its professionals; and, the standard of good practice is of grave concern. The Health Authority is keen to have the involvement of Bekerian as an advisor on applied memory issues and interview techniques as well as determining the successfulness of training procedures in promoting better practice.

The County Crown Prosecution Service (CPS) has also expressed their intention to become directly involved in the project, primarily to provide input regarding the standard of interviewing as seen by legal requirements. As already mentioned the CPS are concerned with the poor quality of interviewing techniques used in child abuse cases. The CPS feel that our project can provide important information about the extent to which poor interviewing is responsible for failures to proceed with or sustain prosecution.

An evaluation of child abuse interviews is also being conducted in Leicestershire by Prof. G. Davies and his colleagues (Psychology Dept. University of Leicester), although the work has not yet begun. Prof. Davies has expressed interest in the procedures that we have developed for analyses of evidential interviews and further collaborative work is under discussion.

MEMORY AND AGEING *(Maylor)*

Introduction

Since my arrival at the APU in September 1992, I have continued research begun at the Age and Cognitive Performance Research Centre in Manchester. This work is primarily concerned with attempts to characterise differences in normal ageing: (i) between tasks, (ii) within tasks, and (iii) between individuals. Of particular interest is the concept of "limited impact": it may be possible to identify aspects of performance and/or individuals within a population apparently unaffected by ageing. Some of the methods used have been successfully applied in previous work on the effects of moderate doses of alcohol in healthy young adults (e.g., Rabbitt & Maylor, 1991; Maylor et al., 1992; Maylor & Rabbitt, 1993). A central issue in both areas of research is the extent to which a single factor such as reduced processing resources can account for changes in performance. For example, in speeded tasks, the question is whether the effects of old age are generally proportionate: that is, these effects may be larger in absolute terms for tasks, stimuli, or people that take longer, but are not necessarily larger in relative terms.

A. Retrieval from Long-Term Memory

It is generally assumed that normal ageing is associated with markedly-decreasing fluid intelligence (the efficiency of processing at the time of evaluation), but relatively-stable crystallised intelligence (the accumulated products of prior processing). However, it is not always the case that measures of vocabulary or general knowledge (as tests of crystallised intelligence) remain stable with increasing age. For example, there is significant age-related decline in the ability to identify a word from its definition when retrieval time is limited (Maylor, 1990b), despite age-matching on the ability to define words. It appears, therefore, that the elderly are more impaired in accessing the lexical system from the semantic system than the reverse. This is consistent with complaints by the elderly of increasing numbers of "tip-of-the-tongue" states, particularly associated with self-reported difficulty in retrieving people's names (e.g., Maylor, 1993; 3.71).

In laboratory studies of the identification of famous people from photographs (Maylor, 1990c), and television programmes from theme tunes (Maylor, 1991), the elderly are significantly impaired at recognition, naming and retrieval of semantic information. Moreover, the effect of age is more dramatic at later stages of the identification process than at earlier stages (naming and recognition, respectively). Older adults are slower than younger adults in making structural, recognition, semantic and naming decisions about faces, with the age difference in latency varying across tasks (larger for slower tasks). To examine whether this effect of ageing is simply proportionate (i.e., older adults are generally slower than younger adults by a constant proportion), the data are redrawn as a Brinley plot, in which response latencies from older subjects are plotted against the corresponding latencies from younger subjects. The resulting function is linear with a slope greater than 1, and this true for both between- and within-task variability (Maylor & Valentine, 1992).

In contrast to this pattern of proportionate slowing for choice decisions about faces, the pattern for name retrieval is disproportionate (positively accelerated) for more difficult items. This is attributable to an increased probability of retrieval blocks with age (Maylor & Valentine, 1992) that occurs for both proper and common names

The question of individual differences in ageing was addressed by studying older and younger volunteers selected as "experts" in speeded retrieval of information from long-term memory (3.63). In contrast to the earlier findings from more representative samples of the population, tip-of-the-tongue states (while retrieving either specialised or general knowledge) were no more likely to occur in the older experts than in the younger experts, suggesting that age-related decline is not inevitable but may be related to initial level of performance (see also 3.66).

Finally, two studies of long-term memory retrieval demonstrate specific age-related loss of contextual information. The first was a collaborative study conducted with Gillian Cohen (Open University) and Martin Conway (Bristol University). A year after the event, very few elderly subjects reported "flashbulb" memories for the circumstances in which they learned of Margaret Thatcher's resignation, in comparison with younger subjects (3.38). The second study examined long-term memory for auditory stimuli; there was age-related decline in recognition accompanied by recollective experience of the original learning context, but no age effect in the absence of recollective experience (3.65).

B. Prospective Memory

The ability to perform successfully in prospective memory tasks, such as remembering to pay an electricity bill on time, or to take medicine every four hours, is obviously essential for independent living. Until recently, however, prospective memory has been a somewhat neglected area of research within cognitive psychology. There are probably both practical and theoretical reasons for this, including the problems of distinguishing between memory failures and lack of compliance, between prospective and retrospective components of a task, and so on.

With regard to age and prospective memory, the elderly would not be expected to perform as well as the young because of their reduced processing resources. In particular, deficits in processes such as self-initiated retrieval, reality monitoring and output monitoring would be detrimental to performance in prospective memory tasks. However, experience and feedback accumulate with age, providing the opportunity for the elderly to develop compensatory strategies to overcome their cognitive deficits. This could account (at least partly) for the striking absence of age deficits in (1) "naturalistic" prospective memory studies conducted outside the laboratory (Maylor, 1990a), and (2) self-rated ability in everyday prospective memory tasks (Maylor, 1993). Consistent with their declining cognitive abilities, the elderly are less able to perform as well as the young under laboratory conditions, where the use of external memory aids is prevented (3.62).

From componential analyses of repeated prospective memory tasks (3.136), it is argued that performance on a particular occasion is influenced by different factors depending on whether the task is being performed for the first time (in which case, behaviour at encoding may predominate) or has already been performed (in which case, memory for the earlier occasion and its context may play an additional role). For example, the type of cue adopted in the task performed outside the laboratory (Maylor, 1990a) was found to have a stronger effect on initial performance (i.e., success or failure on the first occasion) than on subsequent forgetting (i.e., success followed by failure). On the other hand, age was found to have a stronger effect on subsequent forgetting than on initial performance. The relationship between age and forgetting in the laboratory prospective memory task (3.62) is particularly striking for two reasons: (1) it remained significant even after age differences in other measures of performance (including speed) were taken into account, and (2) it contrasts with the absence of an effect of age on forgetting in retrospective memory tasks (e.g., 3.62). Again, these findings illustrate differences in the effects of age both between and within tasks that are difficult to explain in terms of single-factor models.

FUTURE PROPOSALS

A. Retrieval from Long-Term Memory

Preliminary attempts to investigate factors (including age) associated with variability in long-term memory retrieval from one occasion to another were disappointing because of too few instances of successful retrieval followed by failure. Plans to resolve this issue include a considerable increase in the time interval between testing occasions (which has the additional advantage of minimising the influence of episodic memory).

B. Prospective Memory

Thus far, there has been little work on either the reliability or the validity of prospective memory measures. On the question of reliability, it seems plausible, for example, that prospective memory paradigms with multiple observations would be preferable to those with single observations. However, this may be a mistaken assumption, since performance on any given trial in a prospective memory task may not necessarily be independent of performance on previous trials (3.136). Also, some evidence suggests that single observations may be more reliable in the young than in the elderly, the latter group displaying greater variability from trial to trial (3.62). Future plans therefore include examining the relationships between performance in single- and multiple-observation prospective memory paradigms, and between performance in similar tasks on different occasions, both as a function of age.

On the question of validity, one of the more promising laboratory procedures is that of embedding a prospective memory task (e.g., "Remember to note the people wearing glasses") within a demanding retrospective memory task (e.g., "Name the famous faces") (see 3.62, 3.136). It is particularly striking that the reasons given by subjects for failing the prospective memory element correspond well with those given by subjects failing prospective memory tasks outside the laboratory (e.g., "I was absorbed in another task"). This suggests that the former may be a good analogue of the latter; however, it is clearly important to establish more formally that current laboratory paradigms are indeed indicative of competence in everyday prospective memory tasks outside the laboratory. This issue of validity will be investigated by testing the same subjects in a variety of short- and long-term prospective memory tasks, both inside and outside the laboratory, together with detailed diary studies of prospective memory failures. Maylor (1990a) observed a significant (albeit weak) relationship between performance on two nonlaboratory prospective memory tasks, but this was possibly due to the use of a common strategy. The use of cues will therefore be prohibited or controlled for in the analyses. Finally, age comparisons across different prospective memory tasks remain to be performed. It has been suggested that age effects should be particularly evident in time-based prospective memory tasks in which environmental support is low and self-initiated activity (e.g., clock-monitoring) is high. Age deficits should be less apparent in event- and activity-based tasks (greater environmental support available and less self-initiated activity required). Also, we need to explore possible interactions between ageing and the cognitive demands of the ongoing activity that has to be interrupted to fulfil the requirements of the prospective memory task.

C. Analysis of Performance Distributions

In a recent article (3.66), Maylor & Rabbitt described the application of Brinley plots to performance distributions from two speeded tasks. Response times within each of two age groups were ranked and then plotted against each other, so that the best younger adult was paired with the best older adult, and so on. For both tasks, linear fits to the functions were almost perfect, with slopes greater than 1 and negative intercepts; these parameters were shown to be significantly different in the two tasks. First, it should be noted that although the data were cross-sectional, they were at least consistent with the possibility that slower adults are more affected by ageing than faster adults in absolute terms but not in relative terms (c.f. Maylor & Rabbitt, 1993, for a similar conclusion with regard to alcohol). Second, this novel approach demonstrates the use of within-group variability to reveal between-task differences in the effects of ageing. Thus far, the method has been applied only to speeded tasks, namely, letter coding and visual search. However, there is clearly potential to explore its applicability to non-speeded memory tasks, with the possibility of observing dissociations with age that have not necessarily been found in analyses based on group means (for example, between verbal and spatial material, and between memory for location and identity).

D. Dual Tasks

Age deficits in working memory are well-documented. Postural stability is also known to decline significantly in old age. Preliminary findings indicate that cognitive tasks which require particular components of working memory produce a more detrimental effect on standing balance in the elderly than in the young; further studies are planned to investigate these interactions and their possible consequences in more detail (see Perception and Action programme).

PROSPECTIVE MEMORY *(Sellen)*

A. Technology in Support of Human Memory

Over the past two years, Sellen has worked in collaboration with Rank Xerox EuroPARC, Cambridge, on the design of technological aids for supporting memory in the workplace. EuroPARC has in place a system of "Active Badges" — lightweight, wearable devices which emit an infra-red signal, picked up by sensors placed around the building. When people wear these badges, the system can automatically track and record people's activities, and send them a personal electronic "diary". The designers of this system (see Lamming & Newman, 1992) were hopeful that this would form the foundation of a memory "prosthesis", helping to support people's autobiographical memory.

In order to assess the utility of the system, Sellen collaborated on a diary/ questionnaire study of everyday memory problems in order to document the range of memory problems that occur in the workplace, and to assess their frequency and severity (3.148). One of the most striking findings from this study was the high percentage of "prospective" memory problems which occurred — problems of forgetting to carry out intentions. In response to this, Sellen designed and implemented a prototype reminding system to run on devices called PARC "Tabs". Tabs are more sophisticated versions of Badges, having touch-sensitive screens, and the capability of both transmitting and receiving information. This protoype is currently being implemented and integrated into the larger system, now called "Forget Me Not" (described in 3.57).

B. Memory for Intentions*(Sellen, Wilkins)*

Theoretical aspects of prospective memory were investigated in an experiment that made use of the Active Badge technology (3.100). Subjects' prospective memory performance was automatically recorded over the course of two weeks, in the context of their everyday work, by asking them to remember to press the button on their badge either every two hours (time task) or whenever they entered a particular room (place task). The results provided evidence for two different kinds of cognitive mechanism underlying prospective memory: internal, self prompting, and external, contextual cueing. In addition, the electronic diaries revealed that making transitions between different physical locations gave rise to more thoughts about the to-be-performed tasks than settling in any one location. This experiment underlines the importance of examining prospective memory in real world contexts, and shows how new technology can enable the systematic study of these kinds of memory phenomena.

FUTURE PROPOSALS

A. Technology in Support of Human Memory

The integration of the reminding prototype into the "Forget Me Not" system at EuroPARC marks the end of Sellen's involvement in this project. The details are now in the hands of the implementors. In addition, the technological infrastructure necessary to support this system is currently being installed in the Computer Science Department at the University of Toronto. Prof. Bill Buxton has suggested that this also serve as a testing site for the system, and that it be integrated and, if necessary, redesigned, as a result of its use there.

B. Memory for Intentions

Using the technology in place at EuroPARC, further experiments will investigate the cognitive processes underlying memory for intentions. Of particular interest is the frequency with which thoughts about intentions are brought to mind in time-based remembering tasks. With no specific external cue available to trigger the remembering of time-based intentions, it is unclear how remembering on the basis of time occurs. The work so far has suggested that the frequency of thoughts in time-based tasks, is, to some extent, under an individual's control, and that self-prompting is necessary precisely because externally imposed cues are not available.

To test the hypothesis that reliance on an external reminder decreases the amount of internal, self-prompting necessary, we plan an experiment similar to Sellen et. al (3.100) in which subjects at EuroPARC are again assigned the task of pressing a button on their Active Badges at pre-specified time intervals. This time, however, they will be given audio reminders either at the moment when they should perform the task, or at various time intervals before this moment, during the course of their working week. In a different week, subjects will be given no reminder at all. We will analyse the frequency of reported thoughts about the Time task, expecting to observe an increased level of self-initiated thoughts in the "no reminder" condition. The distribution of thoughts according to the variable interval for the time reminders will also be informative about the relationship between reminders and intentions. In addition, the Time task will be designed to be performed at more frequent intervals, so that we can gather more data than in the first experiment. For example, we would like to know if worrying or thinking about the task actually improves prospective memory performance.

MEMORY FOR PEOPLE *(A Young)*

Introduction

As A. Young joined the APU in September 1993, this report is largely based on 6 months work. A principal focus has been disorders of face memory after brain injury (Young, 1992), and particularly the extent to which prosopagnosia (neurologically-based inability to recognise familiar faces) can be considered a highly selective impairment of face memory.

A fundamental issue in visual cognition is whether the stored representations describing the appearances of known visual stimuli are separate from the representations used in perceiving those stimuli. For approaches such as Marr's (1982), recognition is a two-stage process in which a percept is created to describe a seen object's three-dimensional structure and then matched against a catalogue of the structures of known objects. This distinction between the visual percept and the stored representation of a familiar object is elided in some of the presently fashionable connectionist approaches, which emphasise the point that there are circumstances in which same network can be used in responding to novel stimuli and to those already learnt (McClelland & Rumelhart, 1988).

A. Neuropsychological Impairments*(Young, de Haan, Hellawell, Humphreys, Riddoch)*

Impairments of familiar face recognition provide a useful empirical means for examining these competing theoretical claims. At present, many researchers think that there is an underlying difference between cases in which prosopagnosia reflects a perceptual impairment which is sufficiently severe to prevent recognition, and cases in which there is impaired face memory, in the sense of loss of stored knowledge of the appearances of familiar people (De Renzi, Faglioni, Grossi & Nichelli, 1991; McNeil & Warrington, 1991). Others, however, have argued that this perceptual vs. mnestic distinction is actually an idealisation of a unitary problem that can vary in degree of severity, with the apparently perceptual cases simply being the more severely impaired (Levine & Calvanio, 1989).

One key to whether there are qualitatively different types of face recognition impairment may lie in face imagery. It is widely believed that imagery requires access to the same stored knowledge of appearances as is needed for recognition, from which it would follow that imagery abilities can be used to test access to this stored knowledge. A study has therefore investigated face imagery for two patients already well-documented in the research literature, HJA and PH, who experience profound difficulties in recognising familiar faces (3.93). For all face imagery tasks, PH's overall performance was severely impaired. HJA, though, showed preserved face imagery when imaging single faces and when making feature-based comparisons between imaged faces. The interest of these findings lies in the fact that, although HJA's imagery abilities are better preserved than PH's, it is HJA who has the more widespread and severe recognition impairment. HJA has a perceptual impairment that compromises the integration of features into a coherent representation, leaving him unable to recognise many everyday objects as well as familiar faces, and he has not shown any evidence of covert recognition of faces in indirect tests (Humphreys, Troscianko, Riddoch, Boucart, Donnelly & Harding, 1992). PH, by contrast, does not experience any obvious recognition problems for most everyday objects in his daily life, and has been found to show extensive covert recognition effects with familiar faces (de Haan, Young & Newcombe, 1987; Young & de Haan, 1992).

These observations are important to the debate as to whether prosopagnosia is a unitary or a multi-stage disorder. If both patients' visual recognition difficulties are due to the same form of underlying problem (albeit differing in severity), then one must predict that, since HJA's visual recognition problems are more severe than PH's, HJA's face imagery will also be the more severely impaired. Since this is the reverse of what has been found, the results create severe problems for any account assuming a single underlying deficit. In contrast, they can be explained quite simply if it is accepted that impairments of face recognition can have different causes.

Further work in the last 6 months has involved reviews of the literature on face recognition (Young, 1994b) and the relation between recognition mechanisms and awareness (Young, 1994a; Young, 1994c). This latter line of work arises from observations of preserved priming effects from faces which are not consciously recognised in cases of prosopagnosia (de Haan, Young & Newcombe, 1991a). These findings of covert recognition in prosopagnosia show a striking parallel to phenomena of implicit memory in cases of amnesia (Schacter, 1987). The existence of such parallels between prosopagnosia and amnesia has been one of the main reasons for considering some cases of prosopagnosia as a domain-specific memory impairment.

B. Experiments with Normal Subjects *(Young, Ellis, Flude, Hellawell)*

A series of experiments examining the nature of semantic priming effects in the recognition of familiar people has been completed (3.92). Priming effects have provided useful ways of examining the organisation of mechanisms involved in the recognition of familiar people (Ellis, 1992), and they are also turning out to be useful in neuropsychological work (Burton, Young, Bruce, Johnston & Ellis, 1991). In particular, comparisons of repetition and semantic priming have been instructive.

Repetition priming involves the facilitation of recognition by a previously recognised stimulus with the same identity. For example, recognition of the comedian Mel Smith's face is faster if his face has appeared previously in the experiment than if it has not come up before (Bruce & Valentine, 1985). Repetition priming effects are long-lasting (being found across intervals of several minutes in existing published studies, and as long as three months in as yet unpublished work of our own) and domain-specific (except at very short time intervals, recognition of Mel Smith's face is not facilitated by a recent encounter with the name 'Mel Smith').

Semantic priming involves the facilitation of recognition by a previously recognised stimulus with a different, but semantically related, identity. For example, recognition of Mel Smith's face may be faster if the face of Griff Rhys-Jones (who often performs with him) has appeared previously in the experiment (Bruce & Valentine, 1986). In contrast to repetition priming effects, the facilitation produced by semantic priming is very short-lived (generally dissipating within seconds), yet can cross stimulus domains (for example, from recognition of Mel Smith's face to recognition of Griff Rhys-Jones's name).

These differences between repetition priming and semantic priming effects are widely taken to indicate that the sources of facilitation arise at different loci in the recognition system, but more precise specification of the underlying reasons for the differences has proved difficult. However, a considerable advance has been made with the development of an interactive activation implementation of a variant of the Bruce and Young (1986) model of face recognition by Burton, Bruce and Johnston (1991). This interactive activation model is able to simulate the effects of repetition and semantic priming, and the differences between them.

Experiments have shown that repetition and semantic priming have different loci in the recognition system, and that there is no facilitation of decisions for which the identity of the stimulus does not need to be accessed (3.92). We also demonstrated that an important contribution to semantic priming effects is made by associative relatedness (recognition of Eric Morecambe's face is facilitated by having just seen Ernie Wise), rather than category membership per se (recognition of Eric Morecambe's face is not facilitated by having just seen any comedian other than Ernie Wise), and extended this observation by comparing associative priming and priming from the 'same person' in a cross-domain (face prime, name target) paradigm. These results are consistent with the interactive activation simulation developed by Burton et al., (1991), and set constraints which will have to be met by any other plausible account of semantic priming.

FUTURE PROPOSALS

Introduction

Future work aims to explore retrograde and anterograde components of face memory, and their relation to semantic memory for people. As in past work, a combination of investigations of normal people and clinical cases will be employed. Work with neuropsychological cases must always be somewhat opportunistic, since it depends on the availability and willingness of suitable volunteers; this has not been a major problem in the past, despite the rarity of some of the conditions investigated.

Investigations of face processing present an important opportunity to study some of our most highly developed visual abilities with stimuli that are rich in social meaning. The apparent ease with which we recognise faces can, however, be deceptive. In fact, there are many occasions when misidentifications and other forms of error can happen (Young, 1993). The starting point for planned future work is thus the observation that failures of recognition can be quite orderly, which applies in everyday life (Young, Hay & Ellis, 1985) and for recognition failures in the laboratory (Hay, Young & Ellis, 1991). More recently, converging evidence from neuropsychological case studies (de Haan, Young & Newcombe, 1991b; Flude, Ellis & Kay, 1989; Young, 1992) indicates that the functional organisation of the face recognition system involves sequential access to different types of information. Recent theoretical work has therefore concentrated on providing a simulation of how this is might be achieved (Burton & Bruce, 1993).

Although all of this represents useful progress, there are some noticeable rough edges requiring more detailed attention. For example, it has often been noted that much of the functional modelling enterprise has ignored issues of learning. Recent simulation work has sought to correct this oversight (Burton, in press), but learning remains under-investigated in neuropsychology. A detailed examination of retrograde and anterograde components of face memory after brain injury will therefore be useful.

A. Neuropsychological Impairments *(Young)*

Particularly relevant neuropsychological conditions include prosopagnosia, and what Ross (1980) calls visual recent memory loss.

A1. Anterograde Impairments in Prosopagnosia, and Visual Recent Memory Loss: It is widely held that some cases of prosopagnosia reflect impaired face memory, in the sense of damage to pre-morbidly acquired representations of the appearances of familiar people. If so, they usually involve a combination of dense retrograde and anterograde impairments. In many published reports, the retrograde loss is so severe that hardly any premorbidly familiar faces can be recognised overtly, and performance on anterograde face memory tests, such as the Faces part of the Warrington Recognition Memory Test (Warrington, 1984), is at chance.

In some types of simulation (Burton, in press), this combination of retrograde and anterograde impairments might well be considered unsurprising, because both defects would arise from a common locus of damage. However, it is also possible to find cases of impaired anterograde memory for faces in which there is no retrograde loss, and premorbidly familiar faces are recognised without difficulty. Damasio and his colleagues refer to these as 'anterograde prosopagnosias' (Tranel & Damasio, 1985), whereas others prefer the more clumsy but neutral term 'visual recent memory loss' (Ross, 1980).

These cases of impaired anterograde memory for faces are important theoretically, because they imply that full prosopagnosia might reflect a combination of separable anterograde and retrograde impairments. This would constrain theories of the type of learning mechanism involved, but it would depend on a convincing demonstration that the anterograde impairments found in prosopagnosia and visual recent memory loss arise for the same reasons. Thus both conditions require more detailed investigation.

An additional reason for interest in anterograde memory for faces is that, for a thoroughly studied case of loss of visual recent memory (Hanley, Pearson & Young, 1990; Hanley, Young & Pearson, 1991), the defect was found to coincide with impairment of the visuo-spatial sketchpad. This would be predicted by Baddeley's (1986) working memory model, in which the visuo-spatial sketchpad plays a role in new visual learning. Further single-case studies of visual recent memory loss are therefore planned, to determine whether this link to impairment of the visuo-spatial sketch pad forms a common feature, to explore in more detail the relation of the problem to the anterograde memory deficit found in cases of prosopagnosia, and to determine whether any involve face-specific memory deficits. For the latter purpose, parallel versions of Warrington's Recognition Memory Test (Warrington, 1984) are being developed, involving a wider range of stimulus materials. Of course, one cannot ever prove that an anterograde impairment is confined exclusively to stimulus class x, because it is always possible to think of some stimulus class y which happened not to be tested. But the tactic of testing a range of materials should be useful. At present, it is known that patient ELD (Hanley et al., 1990; Hanley et al., 1991), was poor at learning other new visual materials as well as faces, and this is consistent with an account in terms of impairment of the visuo-spatial sketchpad. It will be important to discover whether more selective cases exist.

A2. Retrograde Impairments in Prosopagnosia and Semantic Memory Loss: An obvious implication of the hypothesis that prosopagnosia is a combination of separable anterograde and retrograde face memory impairments is that, as well as Damasio's anterograde prosopagnosias, a purely retrograde form might exist. Although this has never been reported, cases of gradual recovery from prosopagnosia have occasionally been noted. This gradual recovery would be consistent with an impairment affecting only retrograde face memory, though it can also be explained in other ways. The crucial test will be to determine whether recovery extends to all premorbidly familiar faces, or only to those faces encountered postmorbidly.

A second general area concerns the relation between memory representations involving facial appearance and personal semantic characteristics. In neuropsychological studies, there is a clear contrast between prosopagnosic cases, in which recognition from the face is impaired but recognition from other cues (such as the person's name) remains relatively unaffected, and cases which reflect a more central loss of semantic information concerning familiar people, who show inability to recognise people from face, name or voice (Ellis, Young & Critchley, 1989; Hanley, Young & Pearson, 1989). This latter type of problem has not yet attracted a lot of attention, despite the increase in interest in other aspects of semantic memory. Effects of quite basic properties, such as frequency of encounter and age of initial learning, need to be explored. Development of appropriate techniques could form part of a more general investigation of recent claims that age of acquisition affects the naming of seen objects and words but not their recognition (Morrison, Ellis & Quinlan, 1992). Faces and people's names form useful stimuli for this purpose, since new examples are being learnt throughout life.

B. Experiments with Normal Subjects *(Young, Calder)*

B1. Priming Effects: Part of the reason for the relatively scant investigation of neuropsychological cases involving loss of semantic information concerning familiar people lies in the lack of suitable methods which can be imported from experimental work. Effort will therefore be devoted to research on normal people which could provide the basis for such techniques. This would include further investigation of priming effects using predictions derived from the Burton et al. model (Burton, Bruce & Johnston, 1990) and possible alternatives (Brédart, 1993; Valentine, Moore, Flude, Young & Ellis, 1993). Particular attention will be given to the phenomenon of self priming (3.92) which involves cross-domain facilitation of recognition of the same person (for example, seeing John Major's face primes recognition of the target name 'John Major'). This effect is particularly useful in neuropsychological work, and it provides an interesting test of the Burton et al. model (Burton et al., 1990), which predicts its time course and other properties.

B2. Mapping of Visual and Semantic Descriptions of Familiar People: An important question in face recognition is whether the visual representations used to recognise familiar faces are abstract descriptions of the essential properties of a particular face's structure, or are better considered as accretions of individually encountered instances in which the face was seen (Young & Bruce, 1991). An equivalent issue arises concerning the nature of semantic representations, which are treated in a highly abstract way in some current models of person recognition (Burton et al., 1990). For this reason, the extent to which semantic representations of familiar people remain linked to, or become independent of, the circumstances in which they were learnt will be investigated. For example, people's appearances change markedly throughout their lives, yet it is not known whether access to a fact about a person learnt when s/he was aged 20 (for example, that Cliff Richard sang 'Living Doll') will be more readily cued by a contemporary picture (Cliff with his quiff) than a picture of the same face from a different era (Cliff Richard now). Abstractive models predict no difference in matching Cliff Richard's face at age 20 and his face at age 50 to the facts that he sang Living Doll and now wants to be Heathcliff. In contrast, instance-based models predict a crossover interaction: for Cliff Richard's face at age 20, verifying that he sang Living Doll should be faster than verifying that he wants to be in Wuthering Heights; for Cliff Richard's face at age 50, the reverse would apply.

DISORDERS OF SEMANTIC MEMORY *(K Patterson)*

Introduction

Semantic memory is psychology's term for the component of long-term memory that represents knowledge rather than memories of specific events or episodes. The goal of this research is to advance our understanding of semantic memory by studying its deterioration in two types of neurodegenerative disease: semantic dementia, which appears to be a distinct syndrome selectively affecting semantic memory, and dementia of the Alzheimer's type (DAT). Although my principal interest in semantic memory disorders relates to their impact on language processes (see K Patterson's section in the Language and Communication Programme), certain issues regarding semantic memory per se are (as a result of a collaboration with Dr J R Hodges in the Neurology Department) becoming part of my research programme. We are using evidence from the breakdown of semantic memory to ask such questions as (i) how semantic memory, as a whole 'module' or as sub-systems defined by different types of knowledge, is neuroanatomically localised in the brain; (ii) whether semantic and episodic memory are truly separable memory systems; and (iii) how semantic information is organised with regard to different types of knowledge, e.g. for objects as compared to words, for information relating to different sensory systems, etc.

A. Neuroanatomy of Semantic Memory

A1. Semantic Dementia: To date, few identified cases of semantic dementia have come to post mortem; but in all of these, the affected areas have been predominantly in the temporal lobes (Hodges, 1993; Snowden et al, 1992). Structural (MRI) and functional (PET or SPET) in vivo imaging of patients with semantic dementia have also shown abnormalities almost exclusively in temporal neocortex, either predominantly in the left hemisphere or sometimes bilaterally (3.55). These findings, together with a review of other literature on disorders of semantic memory, have led us to conclude that lateral areas of temporal cortex seem to be crucial to the operation of semantic memory (3.140).

A2. DAT: In DAT, the pathological changes characteristic of the disease begin typically around the medial temporal structures critical for episodic rather than semantic memory (Braak & Braak, 1991); thus the earliest and most profound deficit in DAT is one of episodic memory. As the disease progresses, however, pathology spreads to bilateral posterior association cortex, including the lateral temporal structures that are more selectively affected in semantic dementia. Disrupted semantic memory -- which may be relatively mild, though detectable, in early stages of DAT (3.97) -- then becomes a major feature in later stages (Hodges, Salmon & Butters, 1992).

B. The Episodic / Semantic Distinction

B1. Conceptual Issues: The separability of episodic and semantic memory 'systems' is by no means established. The fact that you know that Paris is the capital of France without being able to retrieve any specific memories of when or where you acquired this knowledge may seem to dissociate semantic from episodic memory; but it might instead only reflect the accumulation of many learning episodes in many different contexts over many years. On the basis of the neuropsychological double dissociation between patients with the amnesic syndrome (who have profoundly disrupted episodic memory with sometimes well preserved semantic memory) and patients with semantic dementia (who have profoundly disrupted semantic memory with apparently well preserved episodic memory), our current working hypothesis is that semantic and episodic memory are in fact separable systems with neuroanatomically and psychologically distinct bases (3.140). The operation of these two components of long-term memory, however, is probably interdependent, in two senses. First, since learning new information necessitates some memory of the event conveying that information, no new semantic memories will be acquired if the brain mechanisms for maintaining episodes are severely compromised. Secondly, since information that is poorly understood is difficult to encode in a durable fashion, no new episodic memories will be acquired if the brain mechanisms for comprehending information are severely compromised.

B2. Empirical Evidence: We have only begun to tackle the problem of assessing the status of episodic memory in patients with semantic dementia. On the Autobiographical Memory Interview (Kopelman et al, 1989), several patients achieved performance within normal limits when relating autobiographical episodes, but were impaired when asked to give personal semantic information (3.55). Kim Graham's thesis research has established that a patient with semantic dementia can perform normally on a recognition memory test (episodic memory) for items from a previously administered semantic memory assessment on which his performance was markedly impaired.

C. Organisation of Semantic Memory

C1. Is Knowledge Organised Hierarchically? In our initial investigations of the organisation of semantic memory, as revealed by the profile of its deterioration in semantic dementia, we have completed two intensive longitudinal single-case studies, each of about 3 years' duration, ceasing at the point when each patient was too impaired to be testable (3.54, 3.96). One major issue is the hypothesis (Warrington, 1975) that concept knowledge is organised hierarchically, with general superordinate knowledge (e.g. that an object is a living creature) at the top of the hierarchy, exemplar knowledge (e.g., of dogs and horses as members of the class of land mammals) in the middle, and very specific attribute knowledge (e.g., dogs eat meat and bark, horses are herbivorous and neigh) at the bottom. Like Warrington's (1975) cases, our two progressive patients have shown a dramatic contrast between relatively preserved performance on tests tapping the more general superordinate aspects of knowledge and marked impairment on the more specific levels, both across tests at a given point in time and in their longitudinal pattern of decline. The interpretation of this contrast is, however, debatable. Our current hypothesis is that it does not imply anything hierarchical about the organisation of semantic knowledge, but rather reflects the natural consequences of loss of specific features from a distributed network of featural knowledge about objects (3.96, 3.140; see also Rapp & Caramazza, 1993). A reduced set of features will support 'higher-level' distinctions, such as that between living and manmade objects, but not more specific ones concerning attributes such as barking/neighing.

C2. Is Knowledge Organised by Category and/or Modality? The literature of the last decade abounds with tantalising descriptions of highly selective disorders of semantic memory (mainly in cases of herpes simplex encephalitis, though also in a few cases of either cerebrovascular accident or head injury). Some disorders are apparently category specific, with a marked contrast between the patient's performance on living things and on man-made objects; typically the superior performance is on objects, but there are just enough reports of an advantage with living things for theorists to propose a double dissociation. Some disorders are apparently modality specific, with a marked contrast between comprehension of objects and of words. Indeed, a few cases showing both effects have led McCarthy (1994) to argue that semantic memory may have four basic quadrants defined by these two primary distinctions between category (natural kind/artefact) and modality (visual/verbal). Interestingly, we have observed only hints of these two distinctions in our cases of either semantic dementia or DAT; and those hints have been in directions explicable on other grounds. For example, better discrimination between living and manmade objects from pictures than from words is understandable because pictures offer structure/function correlations not obvious from word forms.

FUTURE PROPOSALS

A. Neuroanatomy of Semantic Memory

A1. Semantic Dementia: In terms of leading research groups working on this disorder, we are probably one of two in the UK (the other being Drs D Neary and J Snowden at the Manchester Royal Infirmary), and one of four or five in the world. Although semantic dementia is a relatively rare condition, John Hodges is likely to pick up any putative case in the East Anglian Region; and, as our work on this topic is becoming known, relevant patients from other regions are being referred to us. We plan serial in vivo imaging (MRI and SPET) in our longitudinal case studies; with the advent of PET (and possibly functional MRI) in Cambridge, the quality of functional brain imaging will soon be substantially improved. Most patients and their families also agree to donate brain tissue at death and, owing to cooperation with the Cambridge Brain Bank (Dr John Xuereb), we can obtain post-mortem pathological analysis. We therefore have the opportunity, over the next 5 years or so, to make major advances concerning brain-behaviour relationships for semantic memory. Although the imaging and pathology clearly rely on the Addenbrooke's side of the collaboration, the cognitive neuropsychological expertise offered by the APU is an equally vital component of the brain-behaviour equation. For example, in order to determine whether visual and verbal semantic knowledge are neuroanatomically separable, it is essential to have tests (e.g., 3.156) where performance measuring access to knowledge from either pictures or words can be correlated with neuroanatomical data.

A2. DAT: In our current 3-year longitudinal study, for a subset of our cohort of about 50 DAT patients, we have both imaging data and declarations of intent concerning post-mortem brain tissue; and in the planned sequel to this study, imaging will play a more prominent role. One of the central questions to be addressed is the correlation between degree of semantic memory impairment (which is highly variable at mild-to-moderate stages of DAT) and structural/ functional abnormalities of the temporal-lobe structures that, by our hypothesis, are critical for semantic memory.

B. The Episodic / Semantic Distinction

B1. Semantic Dementia: Patients with this syndrome seem ideal for addressing the controversial question of whether these two components of long-term memory really differ in kind or only in degree. If the apparent distinction only reflects the fact that knowledge is the accumulation of many episodes, then semantic memory should be more resistant to brain damage, and the advantage for semantic > episodic memory in patients with the amnesic syndrome would not constitute dramatic evidence for a real dissociation. If, on the other hand, we can demonstrate a significant advantage for episodic > semantic memory in patients with semantic dementia, the case for separability will be stronger. In addition to the neuroanatomical approach to this issue described above, at a purely behavioural level, we plan to expand the two lines of investigation already started (the Autobiographical Memory Inventory (Kopelman et al, 1989), and assessment of patients' episodic memory for recently administered tests of semantic memory; see B2 above), and also to develop some new lines such as Mandler's (1990) technique for assessing episodic memory in preverbal normal infants: the infant observes the experimenter performing a distinctive sequence of actions with a small set of objects and is later given the opportunity to re-enact this sequence and thereby display memory for the event. As this test depends neither upon knowledge of the identity of the objects nor upon comprehension of verbal instructions, we hope that these procedures can be adapted for use with patients at advanced stages of semantic dementia.

C. Organisation of Semantic Memory

C1. Hierarchical and Categorical Organisation: We aim to establish that patients with disrupted semantic memory do consistently achieve greater success on tests or items that tap higher-level, more general knowledge, using both a variety of stimulus materials (words, pictures, objects) and a variety of test paradigms (answering questions, sorting pictures or words, priming). It will be essential to demonstrate that this predicted pattern is not just attributable to differential comprehension of the terms applied to the different levels (Funnell, 1993). For example, we have very recently begun to use sorting tests where, at levels below the discrimination between "living" vs. "manmade" things, we use high-frequency category labels rather than such potentially uncommon terms as "native" vs. "foreign" animal. Preliminary results are encouraging, in the sense that two new semantic dementia patients have shown poor performance in sorting pictures of various instances and breeds into groups labelled "dog" and "cat" (extremely common terms) at the same time as performing well on the higher-level discrimination between living and manmade objects.

We are also, once again, taking inspiration from Jean Mandler's work on conceptual development in normal babies, which suggests that the distinction between living and non-living things is learned very early in development (e.g., Mandler, 1991). This is important both theoretically, for evaluating the possibility that early-acquired knowledge is represented in the brain in a way that makes it more resistant to brain-injury, and also practically, for the application of techniques designed for pre-verbal infants to the assessment of severely impaired patients. One approach involves a habituation technique, in which the subject is handed a series of five toy objects to examine: the first four are always from the same category; on some trials, the fifth in the series is also a member of that category; on other trials it is an instance of a different category. Very young infants look significantly longer at items in position 5 that cross the animal/ object boundary but show little or no discrimination between different types of animals. We are currently testing a pilot version of this procedure with patients who are too impaired to comply with the requirements of explicit sorting or matching tests.

C2. Is Knowledge Organised by Category and/or Modality? Our hypothesis is that these distinctions will eventually be explicable in terms of (a) differences in the manner in which knowledge is originally acquired and (b) differences in the procedures by which information from objects and words is retrieved or computed. We have some tentative plans about how to explore these controversial issues, but cannot guarantee to accomplish them in the near future since none of our current cohort of patients shows either of these distinctions in a prominent form.

C3. Item-Specific Consistency: Consistency can be assessed over time on the same test, where extreme consistency would correspond to the following pattern: there would be a point in the progression of a deficit, before which the patient consistently succeeds (for example) in naming a picture of a rhinoceros, and then, having once failed to name a rhinoceros, never succeeds again. It can also be measured across different tests within one time band, where extreme consistency would mean, for example, that failure to "point to the rhinoceros" in a set of animal pictures should predict that the patient will also fail when asked to name the picture, to answer questions such as "Does a rhinoceros have a horn?", etc. There are substantial statistical problems in measuring both of these forms of consistency, owing to declining baselines over time in the first case and differing levels of difficulty (and of chance performance) for the various tests in the second case.

There are also substantial problems in interpreting statistically reliable degrees of consistency, since -- when considering item-specific consistency between two tests, for example -- performance on both may be strongly modulated by some other factor such as word frequency. We will require considerable statistical assistance from Dr Ian Nimmo-Smith in working out solutions to these measurement/interpretation problems. The goal is a worthy one, however, since the issue of consistency plays a major role in theoretical discussions of semantic disorders, particularly in attempts to identify specific disorders as deficits of either "storage" (i.e., genuine loss of information from the brain system representing that knowledge) or "access" (problems in activating or retrieving knowledge that is still somehow coded in the system) (see Rapp & Caramazza, 1993 and Shallice, 1988, for discussion).

PUBLICATIONS (Excluding work done prior to arrival at APU)

Authored Books

3.1. BADDELEY, A.D. (1990). Human Memory: Theory and Practice. London: Lawrence Erlbaum Associates.

3.2. BADDELEY, A.D. (1993). Your Memory: A User's Guide (2nd edition). London: Lifecycle Publications.

3.3. Gathercole, S.E. & BADDELEY, A.D. (1993). Working Memory and Language. Hove, Sussex: Lawrence Erlbaum Associates.

Edited Books

3.4. Broadbent, D.E., BADDELEY, A.D. & Reason, J.T. (Eds.) (1990). Human Factors in Hazardous Situations. Oxford: Clarendon Press.

3.5. BADDELEY, A. & Weiskrantz, L. (Eds.) (1993). Attention: Selection, Awareness and Control. A Tribute to Donald Broadbent. Oxford: Clarendon Press.

3.6.* BADDELEY, A.D., WILSON, B.A., & WATTS, F. (Eds.) (in press). Handbook of Memory Disorders. Chichester: John Wiley & Sons.

Refereed Articles

3.7. Alberoni, M., BADDELEY, A.D., Della Sala, S., Logie, R. & Spinnler, H. (1992). Keeping track of a conversation: Impairments in Alzheimer's disease. International Journal of Geriatric Psychiatry, 7, 639-646.

3.8. ANDRADE, J. (in press). Learning during anaesthesia: A review. British Journal of Psychology.

3.9. ANDRADE, J. & Meudell, P.R. (1993). Is spatial information encoded automatically in memory? Quarterly Journal of Experimental Psychology, 46A, 365-375.

3.10. ANDRADE, J. & Munglani, R. (in press). Are therapeutic suggestions really therapeutic? (letter to the editor), British Journal of Anaesthesia.

3.11. ANDRADE, J., Munglani, R., Jones, J.G. & BADDELEY, A.D. (1994). Cognitive performance during anaesthesia. Consciousness and Cognition, 3, 148-165.

3.12. BADDELEY, A.D. (1992). Is working memory working? The Fifteenth Bartlett Lecture. Quarterly Journal of Experimental Psychology, 44A, 1-31.

3.13. BADDELEY, A.D. (1992). Working memory. Science, 255, 556-559

3.14. BADDELEY, A.D. (1992). Working memory: The interface between memory and cognition. Journal of

Cognitive Neuroscience, 4, 281-288.
3.15. BADDELEY, A.D. (1993). A theory of rehabilitation without a model of learning is a vehicle without an engine: A comment on Caramazza and Hillis. Neuropsychological Rehabilitation, 3, 235-244.
3.16. BADDELEY, A.D. (1993). Short-term phonological memory and long-term learning: A single case study. European Journal of Cognitive Psychology, 5, 129-148.
3.17. BADDELEY, A.D. (1994). The magical number seven: Still magic after all these years? Psychological Review, 101, 353-356.
3.18. BADDELEY, A.D. & Hitch, G.J. (in press). Developments in the concept of working memory. Neuropsychology.
3.19. BADDELEY, A.D. & ANDRADE, J. (in press). Reversing the word length effect: A comment on Caplan, Rochon and Walters. Quarterly Journal of Experimental Psychology.
3.20. BADDELEY, A.D., Bressi, S., Della Sala, S., Logie, R. & Spinnler, H. (1991). The decline of working memory in Alzheimer's Disease: A longitudinal study. Brain, 114, 2521-2542.
3.21. BADDELEY, A.D., Della Sala, S. & Spinnler, H. (1991). The two-component of memory deficit in Alzheimer's Disease. Journal of Clinical and Experimental Neuropsychology, 13, 373-380.
3.22. BADDELEY, A.D., EMSLIE, H. & NIMMO-SMITH, I. (1993). The Spot-the-Word test: A robust estimate of verbal intelligence based on lexical decision. British Journal of Clinical Psychology, 32, 55-65.
3.23. BADDELEY, A.D. & Hitch, G.J. (1993). The recency effect: Implicit learning with explicit retrieval? Memory and Cognition, 21, 146-155.
3.24. BADDELEY, A.D. & Hitch, G.J. (in press). Developments in the concept of working memory. Neuropsychology.
3.25. BADDELEY, A.D., Meeks Gardner, J. & Grantham-McGregor, S. (in press). Cross-cultural cognition: Developing tests for developing countries. Applied Cognitive Psychology.
3.26. BADDELEY, A.D., PAPAGNO, C. & ANDRADE, J. (1993). The sandwich effect: The role of attentional factors in serial recall. Journal of Experimental Psychology: Learning, Memory, and Cognition, 19, 862-870.
3.27. BADDELEY, A.D. & WILSON, B.A. (1993). A developmental deficit in short-term phonological memory: Implications for language and reading. Memory, 1, 65-78.
3.28. BADDELEY, A.D. & WILSON, B.A. (1994). A case of word deafness with preserved span: Implications for the structure and function of short-term memory. Cortex, 29, 741-748.
3.29. BADDELEY, A.D. & WILSON, B.A. (1994). When implicit learning fails: Amnesia and the problem of error elimination. Neuropsychologia, 32, 53-68.
3.30. BEKERIAN, D.A. (1993). In search of the typical eyewitness. American Psychologist, 48, 574-576.
3.31. BEKERIAN, D.A. (in press). The problems with childhood memories. Consciousness and Cognition: Special Edition on Recovered/False Memories.
3.32. BEKERIAN, D.A. & DENNETT, J.L. (1990). Spoken and written recall of visual narratives. Applied Cognitive Psychology, 4, 175-187.
3.33. BEKERIAN, D.A. & DENNETT, J.L. (1993). The cognitive interview technique: Reviving the issues. Applied Cognitive Psychology, 7, 275-297.

3.34. Bradley, B.P. & BADDELEY, A.D. (1990). Emotional factors in forgetting. Psychological Medicine, 20, 351-355.
3.35. CLARE, L., McKenna, P.J., Mortimer, A.M. & BADDELEY, A.D. (1993). Memory in schizophrenia: What is impaired and what is preserved? Neuropsychologia, 31, 1225-1241.
3.36. Cockburn, J., WILSON, B., BADDELEY, A. & Hiorns, R. (1990). Assessing everyday memory in patients with dysphasia. British Journal of Clinical Psychology, 29, 353-360.
3.37. Cockburn, J., WILSON, B.A., BADDELEY, A.D. & Hiorns, R. (1990). Assessing everyday memory in patients with perceptual deficits. Clinical Rehabilitation, 4, 129-135.
3.38. Cohen, G., Conway, M.A. & MAYLOR, E.A. (in press). Flashbulb memories in older adults. Psychology and Aging.
3.39. da Costa Pinto, A. & BADDELEY, A.D. (1991). Where did you park your car? Analysis of a naturalistic long-term recency effect. European Journal of Cognitive Psychology, 3, 297-313.
3.40. DE WALL, C., WILSON, B.A. & BADDELEY, A.D. (1994). The Extended Rivermead Behavioural Memory Test: A measure of everyday memory performance in normal adults. Memory, 2, 149-166.
3.41. DRITSCHEL, B.H., WILLIAMS, J.M.G., BADDELEY, A.D. & NIMMO-SMITH, I. (1992). Autobiographical fluency: A method for the study of personal memory. Memory and Cognition, 20, 133-140.
3.42. Eldridge, M., BARNARD, P. & BEKERIAN, D. (1994). Autobiographical memory and daily schemas at work. Memory, 2, 51-74.
3.43. Gathercole, S.E. & BADDELEY, A. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? Journal of Memory and Language, 29, 336-360.
3.44. Gathercole, S.E. & BADDELEY, A.D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. British Journal of Psychology, 81, 439-454.
3.45. Gathercole, S.E. & BADDELEY, A.D. (1993). Phonological working memory: A critical building block for reading development and vocabulary acquisition. European Journal of Psychology of Education, 8, 259-272.
3.46. Gathercole, S.E., WILLIS, C.S. & BADDELEY, A.D. (1991). Differentiating phonological memory and awareness of rhyme: Reading and vocabulary development in children. British Journal of Psychology, 82, 387-406.
3.47. Gathercole, S.E., WILLIS, C.S. & BADDELEY, A.D. (1991). Nonword repetition, phonological memory, and vocabulary: A reply to Snowling, Chiat, and Hulme. Applied Psycholinguistics, 12, 375-379.
3.48. Gathercole, S.E., WILLIS, C.S., BADDELEY, A.D. & EMSLIE, H. (1994). The children's test of nonword repetition: A test of phonological working memory. Memory, 2, 103-127.
3.49. Gathercole, S.E., WILLIS, C.S., EMSLIE, H. & BADDELEY, A.D. (1991). The influences of number of syllables and wordlikeness on children's repetition of nonwords. Applied Psycholinguistics, 12, 349-367.
3.50. Gathercole, S.E., WILLIS, C.S., EMSLIE, H. & BADDELEY, A.D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychology, 28, 887-898.
3.51. GREEN, R.E.A. & SHANKS, D.R. (1993). On the existence of independent explicit and implicit learning systems: An examination of some evidence. Memory and Cognition, 21, 304-317.

3.52. Happel, B.L.M., & MURRE, J.M.J. (in press). The design and evolution of modular neural network architectures. Neural Networks.

3.53. Heemskerk, J.N.H., Hoekstra, J., MURRE, J.M.J., Kemna, L.H.J.G. & Hudson, P.T.W. (1994). The BSP400: A modular neurocomputer. Microprocessors and Microsystems, 18, 67-78.

3.54. Hodges, J., PATTERSON, K. & Tyler, L. (in press). Loss of semantic memory: Implications for the modularity of mind. Cognitive Neuropsychology.

3.55. Hodges, J.R., PATTERSON, K., Oxbury, S. & Funnell, E. (1992). Semantic dementia: Progressive fluent aphasia with temporal lobe atrophy. Brain, 115, 1783-1806.

3.56. KOLODNY, J.A. (1994). Memory processes in classification learning: An investigation of amnesic performance in categorization of dot patterns and artistic styles. Psychological Science, 5, 164-169.

3.57. Lamming, M., Brown, P., Carter, K., Eldridge, M., Flynn, M., Louie, G., Robinson, P., & SELLEN, A. J. (1994). The design of a human memory prosthesis. Computer Journal , Vol. 37, No. 3.

3.58. LEVEY, A.B. & Martin, I. (in press). Human classical conditioning: The status of the CS. Integrative Physiological and Behavioural Sciences.

3.59. Logie, R.H., Zucco, G.M., & BADDELEY, A.D. (1990). Interference with visual short-term memory. Acta Psychologica, 75, 55-74.

3.60. MACLEOD, A.K., WILLIAMS, J.M.G. & BEKERIAN, D.A. (1991). Worry is reasonable: The role of explanations in pessimism about future personal events. Journal of Abnormal Psychology, 100, 478-486.

3.61. Martin, I. & LEVEY, A.B. (1991). Blocking observed in human eyelid conditioning. Quarterly Journal of Experimental Psychology, 43B, 233-256.

3.62. MAYLOR, E.A. (1993). Aging and forgetting in prospective and retrospective memory tasks. Psychology and Aging, 8, 420-428.

3.63. MAYLOR, E.A. (1994). Ageing and the retrieval of specialised and general knowledge: Performance of Masterminds. British Journal of Psychology, 85, 105-114.

3.64. MAYLOR, E.A. (in press b). Effects of aging on the retrieval of common and proper names. Facts and Research in Gerontology.

3.65. MAYLOR, E.A. (in press c). Remembering versus knowing television theme tunes in middle-aged and elderly adults. British Journal of Psychology.

3.66. MAYLOR, E.A. & Rabbitt, P.M.A. (1994). Applying Brinley plots to individuals: Effects of aging on performance distributions in two speeded tasks. Psychology and Aging, 9, 224-230.

3.67. McKenna, P.J., Tamlyn, D., Lund, C.E., Mortimer, A.M., Hammond, S. & BADDELEY, A.D. (1990). Amnesic syndrome in schizophrenia. Psychological Medicine, 20, 967-972.

3.68. Munglani, R., ANDRADE, J., Sapsford, D.J., BADDELEY, A.D. & Jones, J.G. (1993). A measure of consciousness and memory during isoflurane administration: The coherent frequency. British Journal of Anaesthesia, 71, 633-641.

3.69. MURRE, J.M.J. (1992). From plans to mediated actions. Commentary on Bridgeman on consciousness. Psycoloquy, 3 (25), consciousness.10.

3.70. PAPAGNO, C., Valentine, T. & BADDELEY, A.D. (1991). Phonological short-term memory and foreign-

language vocabulary learning. Journal of Memory and Language, 30, 331-347.
3.71. Rabbitt, P., MAYLOR, E., Stollery, B., McInnes, L., Bent, N. & Moore, B. (in press). What goods can self-assessment questionnaires deliver for cognitive gerontology? Applied Cognitive Psychology.
3.72. Salamé, P. & BADDELEY, A. (1990). The effects of irrelevant speech on immediate free recall. Bulletin of the Psychonomic Society, 28, 540-542.
3.73. Schlottmann, A. & SHANKS, D.R. (1992). Evidence for a distinction between judged and perceived causality. Quarterly Journal of Experimental Psychology, 44A, 321-342.
3.74. SHANKS, D. (1990). Connectionism and human learning: Critique of Gluck and Bower (1988). Journal of Experimental Psychology: General, 119, 101-104.
3.75. SHANKS, D. (1990). Connectionism and the learning of probabilistic concepts. The Quarterly Journal of Experimental Psychology, 42A, 209-237.
3.76. SHANKS, D.R. (1990). On the cognitive theory of conditioning. Biological Psychology, 30, 171-179.
3.77. SHANKS, D.R. (1991). Categorization by a connectionist network. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 433-443.
3.78. SHANKS, D.R. (1991). On similarities between causal judgments in experienced and described situations. Psychological Science, 2, 341-350.
3.79. SHANKS, D.R. (1991). A connectionist account of base-rate biases in categorization. Connection Science, 3, 143-162.
3.80. SHANKS, D.R. (1992). Connectionist accounts of the inverse base-rate effect in categorization. Connection Science, 4, 3-18.
3.81. SHANKS, D.R. (1993). Human instrumental learning: A critical review of data and theory. British Journal of Psychology, 84, 319-354.
3.82. SHANKS, D.R. (1993). Associative versus contingency accounts of category learning: Reply to Melz, Cheng, Holyoak and Waldmann (1993). Journal of Experimental Psychology: Learning, Memory, and Cognition, 19, 1411-1423.
3.83. SHANKS, D. & Dickinson, A. (1990). Contingency awareness in evaluative conditioning: A comment on Baeyens, Eelen and van den Bergh. Cognition and Emotion, 4, 19-30.
3.84. SHANKS, D.R. & Dickinson, A. (1991). Instrumental judgment and performance under variations in action-outcome contingency and contiguity. Memory and Cognition, 19, 353-360.
3.85. SHANKS, D.R., GREEN, R.E.A. & KOLODNY, J. (1994). A critical examination of the evidence for unconscious (implicit) learning. In C. Umilta & M. Moscovitch (Eds.), Attention and Performance XV: Conscious and Nonconscious Information Processing. Cambridge, MA: MIT Press.
3.86. Shaw, G.A. & BEKERIAN, D.A. (1991). Hypermnesia for high-imagery words: The effects of interpolated tasks. Memory and Cognition, 19, 87-94.
3.87. Tamlyn, D., McKenna, P.J., Mortimer, A.M., Lund, C.E., Hammond, S. & BADDELEY, A.D. (1992). Memory impairment in schizophrenia: Its extent, affiliations and neuropsychological character. Psychological Medicine, 22, 101-115.
3.88. TEASDALE, J.D., Proctor, L., LLOYD, C.A. & BADDELEY, A.D. (1993). Working memory and stimulus-

independent thought: Effects of memory load and presentation rate. European Journal of Cognitive Psychology, 5, 417-433.
3.89. Vallar, G., PAPAGNO, C. & BADDELEY, A.D. (1991). Long-term recency effects and phonological short-term memory: A neuropsychological case study. Cortex, 27, 323-326.
3.90. WILSON, B.A. & BADDELEY, A.D. (1993). Spontaneous recovery of impaired memory span: Does comprehension recover? Cortex, 29, 153-159.
3.91. WILSON, B.A., BADDELEY, A.D., SHIEL, A. & Patton, G. (1992). How does post-traumatic amnesia differ from the amnesic syndrome and from chronic memory impairment? Neuropsychological Rehabilitation, 2, 231-243.
3.92. YOUNG, A.W., Flude, B.M., Hellawell, D.J. & Ellis, A.W. (1994a). The nature of semantic priming effects in the recognition of familiar people. British Journal of Psychology, 85.
3.93. YOUNG, A.W., Humphreys, G.W., Riddoch, M.J., Hellawell, D.J. & de Haan, E.H.F. (1994b). Recognition impairments and face imagery. Neuropsychologia, 32, 693-702.
Submitted
3.94. BADDELEY, A.D., EMSLIE, H., KOLODNY, J. & DUNCAN, J. Random generation and the executive control of working memory. (Manuscript submitted to Journal of Experimental Psychology: Learning, Memory, and Cognition).
3.95. DRITSCHEL, B.H., BEKERIAN, D.A. & TOPLIS, R. Retrieving autobiographical memories to problems. (Manuscript submitted to Memory).
3.96. Hodges, J.R., Graham, N. & PATTERSON, K. Charting the progression in semantic dementia: Implications for the organisation of semantic memory. (Manuscript submitted to Memory)
3.97. Hodges, J.R. & PATTERSON, K. Is semantic memory consistently impaired early in the course of Alzheimer's disease? Neuroanatomical and diagnostic implications. (Manuscript submitted to Neuropsychologia).
3.98. Morris, R.G., Abrahams, S., BADDELEY, A.D. & Polkey, C.E. Doors and People: Visual and verbal memory following unilateral temporal lobectomy. (Manuscript submitted to Neuropsychologia).
3.99. Russo, R. & ANDRADE, J. The directed forgetting effect in word fragment completion: An application of the process dissociation procedure. (Manuscript submitted to Quarterly Journal of Experimental Psychology).
3.100. SELLEN, A.J., Louie, G., Harris, J.E., & WILKINS, A. What makes intentions come to mind? An in situ study of prospective memory. Submitted to Memory & Cognition.
3.101. Shaw, G., BEKERIAN, D.A. & McCubbin, J. Effects of video violence on hypermnesia for imaginally encoded concrete and abstract words. (Manuscript submitted to Memory)
Invited Chapters and Commentaries
3.102. ANDRADE, J. (in press). Is learning during anaesthesia implicit?: Commentary on Shanks & St. John. Behavioral and Brain Sciences.
3.103. BADDELEY, A.D. (1990). The development of the concept of working memory: Implications and contributions of neuropsychology. In G. Vallar & T. Shallice (Eds.), Neuropsychological Impairments of Short-Term Memory (pp. 54-73). Cambridge: Cambridge University Press.

3.104. BADDELEY, A.D. (1991). Human learning and memory. In A. Öhman & B. Öhngren (Eds.), Two Faces of Swedish Psychology: Frontiers in Perception and Cognition. An Evaluation of Swedish Research in Cognitive Psychology (pp. 133-142). Uppsala, Swedish Science Press.
3.105. BADDELEY, A.D. (1992). Cognitive function and whipworm infection. Parasitology Today, 8, 394-295.
3.106. BADDELEY, A.D. (1992). Consciousness and working memory. Consciousness and Cognition, 1, 3-6.
3.107. BADDELEY, A.D. (1992). Implicit memory and errorless learning: A link between cognitive theory and neuropsychological rehabilitation? In L.R. Squire & N. Butters (Eds.), Neuropsychology of Memory (2nd Edition) (pp. 309-314). New York: Guilford Press.
3.108. BADDELEY, A.D. (1992). Memory theory and memory therapy. In B.A. Wilson & N. Moffat (Eds.), Clinical Management of Memory Problems (Second edition) (pp. 1-31). London: Chapman & Hall.

3.109. BADDELEY, A.D. (1992). What is autobiographical memory? In M.A. Conway, D.C. Rubin, H. Spinnler & W.A. Wagenaar (Eds.), Theoretical Perspectives on Autobiographical Memory (pp. 13-29). The Netherlands: Kluwer Academic Publishers.
3.110. BADDELEY, A.D. (1993). Holy war or wholly unnecessary? Some thoughts on the "conflict" between laboratory studies and everyday memory. In G.M. Davies & R.H. Logie (Eds.), Memory in Everyday Life (pp. 532-536). Amsterdam: Elsevier Science Publishers B.V.
3.111. BADDELEY, A.D. (1993). Working memory and conscious awareness. In A. Collins, S. Gathercole, M. Conway & P. Morris (Eds.), Theories of Memory (pp. 11-28). Hove: Lawrence Erlbaum Associates.
3.112. BADDELEY, A.D. (1993). Working memory or working attention? In A. Baddeley & L. Weiskrantz (Eds.), Attention: Selection, Awareness and Control: A Tribute to Donald Broadbent (pp. 152-170). Oxford: Clarendon Press.
3.113. BADDELEY, A.D. (in press). Is memory all talk? A comment on Edwards, Middleton and Potter. The Psychologist.
3.114. BADDELEY, A.D. (in press). Models of learning and the nature of self: The remembered self and the enacted self: Comments on Wagenaar and on Ross and Buehler. In R. Fivush & U. Neisser (Eds.), The Remembered Self: Sixth Emory Cognition Symposium.
3.115. BADDELEY, A.D. (in press). Working memory: The interface between memory and cognition. In D.L. Schacter & E. Tulving (Eds.), Memory Systems 1994. Cambridge, MA: MIT Press.
3.116. BADDELEY, A., Bressi, S., Della Sala, S., Logie, R. & Spinnler, H. (1990). Deficit progressivo della working memory in dementi di tipo Alzheimer. In D. Salmaso & P. Caffarra (Eds), Normalita E Patologia Delle Funzioni Cognitive Nell'Invecchiamento (pp. 124-131). Franco Angeli.
3.117. BADDELEY, A.D. & Gathercole, S. (1992). Learning to read: The role of the phonological loop. In J. Alegria, D. Holender, J. Junça de Morais & M. Radeau (Eds.), Analytic Approaches to Human Cognition (pp. 153-167). Amsterdam: Elsevier Science Publishers B.V.
3.118. BADDELEY, A.D. & Hitch, G.J. (1993). Working memory. In P.E. Morris & M.A. Conway (Eds.), The Psychology of Memory, Vol. II (pp. 134-176). Aldershot: Edward Elgar Publishing Company. [Reprinted from 1974]

3.119. BADDELEY, A.D. & Logie, R.H. (1992). Auditory imagery and working memory. In D. Reisberg (Ed.), Auditory Imagery (pp. 179-197). Hillsdale, N.J.: Lawrence Erlbaum Associates.
3.120. BADDELEY, A.D. & Warrington, E.K. (1993). Memory coding and amnesia. In P.E. Morris & M.A. Conway (Eds.), The Psychology of Memory, Vol. II (pp. 417-421). Aldershot: Edward Elgar Publishing Company. [Reprinted from 1973]

3.121. BADDELEY, A.D., PAPAGNO, C. & NORRIS, D. (1991). Phonological memory and serial order: A sandwich for TODAM. In W.E. Hockley & S. Lewandowsky (Eds.), Relating Theory and Data: Essays on Human Memory in Honor of Bennet B. Murdock (pp. 175-194). Hillsdale, N.J.: Lawrence Erlbaum Associates.
3.122. BADDELEY, A.D., Prinz, W., Smith, P.T. & Wagenaar, W.A. (1991). Reflections on the organisation of cognitive psychology in Sweden. In A. Öhman & B. Öhngren (Eds.), Two Faces of Swedish Psychology: Frontiers in Perception and Cognition. An Evaluation of Swedish Research in Cognitive Psychology (pp. 161-168). Uppsala, Swedish Science Press.
3.123. BADDELEY, A.D., Thomson, N. & Buchanan, M. (1993). Word length and the structure of short-term memory. In P.E. Morris & M.A. Conway (Eds.), The Psychology of Memory, Vol. II (pp. 177-191). Aldershot: Edward Elgar Publishing Company. [Reprinted from 1975]
3.124. BADDELEY, A.D., Thornton, A., Chua, S.E. & McKenna, P. (in press). Schizophrenic delusions and the construction of autobiographical memory. In D.C. Rubin (Ed.), Constructing our Past: Autobiographical Memory. New York: Cambridge University Press.
3.125. BEKERIAN, D.A. & DENNETT, J.L. (1992). The truth in content analyses of a child's testimony. In F. Lösel, D. Bender & T. Bliesner (Eds.), Psychology & Law - International Perspectives (pp. 335-344). Berlin: Walter de Gruyte.
3.126. BEKERIAN, D.A. & DENNETT, J.L. (in press). An introduction to the cognitive interview technique. In T. Ney (Ed.), Allegations in Child Sexual Abuse: Assessment and Management. New York: Brunner/Mazel.
3.127. BEKERIAN, D.A. & DENNETT, J.L. (in press). Assessing the truth in children's statements. In T. Ney (Ed.), Allegations in Child Sexual Abuse: Assessment and Management. New York: Brunner/Mazel.
3.128. BEKERIAN, D.A. & DENNETT, J.L. (in press). Interview profiles: Establishing how people interview. In G. Davies, S. Lloyd-Bostock, M. McMuran & C. Wilson (Eds.), Psychology and Law: Recent Advances in Research. Berlin: de Gruyter.
3.129. BEKERIAN, D.A., DENNETT, J.L., Hill, K. & Hitchcock, R. (1992). Effects of detailed imagery on simulated witness recall. In F. Lösel, D. Bender & T. Bliesner (Eds.), Psychology & Law - International Perspectives (pp. 302-308). Berlin: Walter de Gruyte.
3.130. BEKERIAN, D.A. & DRITSCHEL, B.H. (1992). Autobiographical remembering: An integrated approach. In M. Conway, D. Rubin, H. Spinnler & W. Wagenaar (Eds.), Theoretical Perspectives on Autobiographical Memory (pp. 135-150). The Netherlands: Kluwer Academic Publishers.
3.131. Dickinson, A. & SHANKS, D.R. (1994). Instrumental action and causal representation. In G. Lewis, D. Premack & D. Sperber (Eds.), Causal Understandings in Cognition and Culture. Oxford: Oxford University Press.

3.132. Gathercole, S.E. & BADDELEY, A.D. (1993). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. In P.E. Morris & M.A. Conway (Eds.), The Psychology of Memory, Vol. II (pp. 192-205). Aldershot: Edward Elgar Publishing Company. [Reprinted from 1989]

3.133. HOUGHTON, G. (1990). The problem of serial order: A neural network model of sequence learning and recall. In R. Dale, C. Mellish & M. Zock (Eds.), Current Research in Natural Language Generation (pp. 287-319). London: Academic Press.

3.134. Lachnit, H., Kimmel, H., Bevill, M., Martin, I., LEVEY, A. & Hamm, A. (1990). Classical conditioning with human subjects. In P.D. Drenth, J.A. Sergeant & R.J. Takens (Eds.), European Perspective in Psychology, Vol. 1, Section V, Cognitive Psychology (pp. 353-368). Chichester: John Wiley & Sons.

3.135. Logie, R.H. & BADDELEY, A.D. (1990). Imagery and working memory. In P.J. Hampson, D.F. Marks & J. Richardson (Eds.), Imagery: Current Developments (pp. 103-128). London: Routledge.

3.136. MAYLOR, E.A. (in press a). Does prospective memory decline with age? In M. Brandimonte, G. Einstein & M. McDaniel (Eds.), Prospective Memory: Theory and Applications. Hillsdale, N.J.: Lawrence Erlbaum Associates.

3.137. McKenna, P. & BADDELEY, A.D. (in press). Memory in schizophrenia. In R. Campbell & M. Conway (Eds.), Broken Memories. Oxford: Blackwell Publishers.

3.138. MURRE, J.M.J. (in press). Connectionism and other approaches to natural computation: An overview. In T. Dijkstra & K. De Smedt (Eds.), Computational Psycholinguistics: Symbolic and Subsymbolic Models of Language Processing. Hemel Hempstead: Harvester Wheatsheaf.

3.139. MURRE, J.M.J. (in press). Neurosimulators. In M.A. Arbib (Ed.), Handbook of Brain Research and Neural Networks. Cambridge, MA: MIT Press.

3.140. PATTERSON, K. & Hodges, J. (in press). Disorders of semantic memory. In A.D. Baddeley, B.A. Wilson & F.N. Watts (Eds.), Handbook of Memory Disorders. Chichester, Sussex: John Wiley & Sons.

3.141. PATTERSON, K. (1991). Learning by association: Two tributes to George Mandler. In W. Kessen, A. Ortony & F. Craik (Eds.), Memories, Thoughts and Emotions: Essays in Honour of George Mandler (pp. 35-41). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Conference Proceedings

3.142. BADDELEY, A.D. (1992). Implications of neuropsychological evidence for theories of normal memory. In Proceedings of International School of Neuroscience course on Neuropsychology: The Neuronal Basis of Cognitive Function, Vol. 2 (pp. 91-101). New York: Thieme Medical Publishers Inc.

3.143. BADDELEY, A.D., Gathercole, S. & PAPAGNO, C. (1991). Short-term phonological memory: A crucial system for language development? In Current Issues in Natural Language Processing. (Proceedings of a Conference held at University of Texas, Feb. 15-16, 1991), Center for Cognitive Science, University of Texas.

3.144. MURRE, J.M.J. (1992). The effects of pattern presentation on interference in backpropagation networks. In Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society (pp. 54-59). Hillsdale, NJ:

Lawrence Erlbaum.
3.145. SHANKS, D.R. (1991). Some parallels between associative learning and object classification. In J.-A. Meyer & S.W. Wilson (Eds.), From Animals to Animats: Proceedings of the First International Conference on Simulation and Adaptive Behavior (pp. 337-343). Cambridge, MA: MIT Press.

Technical Reports and Theses

3.146. BEKERIAN, D.A. & DENNETT, J.L. (1990). Interview Profiles (Parts 1 and 2). Child Sexual Abuse, Joint Investigative Project, Cambs. Police and Social Services.

3.147. BEKERIAN, D.A. & DENNETT, J.L. (1990). Interview Profiles (Part 3). Summaries, Profiles and Final Report. Child Sexual Abuse, Joint Investigative Project, Cambs. Police and Social Services.

3.148. Eldridge, M., SELLEN, A.J. & BEKERIAN, D. (1992). Memory problems at work: Their range frequency, and severity. EuroPARC Technical Report No. EPC-92-103.

3.149. GREEN, R.E.A. (1992). Investigations of intentional and automatic processing in amnesic, healthy elderly and healthy young subjects. Unpublished PhD Thesis, University of Cambridge.

3.150. KOLODNY, J. (1993). Conscious and unconscious processes in learning and memory retrieval. Unpublished PhD Thesis, University of Cambridge.

3.151. SHANKS, D.R. & Gluck, M.A. (1991). Tests of an adaptive network model for the identification, categorization, and recognition of continuous-dimension stimuli. Technical Report No. 9103, Department of Cognitive Science, University of California, San Diego, La Jolla, CA.

3.152. SHANKS, D.R. & St John, M.F. (1992). Characteristics of dissociable human learning systems. Technical Report No. 9203, Department of Cognitive Science, University of California, San Diego, La Jolla, CA.

Tests and Patents

3.153. BADDELEY, A.D., EMSLIE, H. & NIMMO-SMITH, I. (1992). The Speed and Capacity of Language Processing (SCOLP) Test. Bury St Edmunds, Suffolk: Thames Valley Test Company.

3.154. BADDELEY, A.D., EMSLIE, H. & NIMMO-SMITH, I. (in press). Doors and People: A test of visual and verbal recall and recognition. Flempton, Bury St Edmunds: Thames Valley Test Company.

3.155. Kopelman, M., WILSON, B. & BADDELEY, A.D. (1990). The Autobiographical Memory Interview. Thames Valley Test Company.

3.156. Howard, D. & PATTERSON, K. (1992). Pyramids and Palmtrees: A test of semantic access from words and pictures. Bury St Edmunds, Suffolk: Thames Valley Test Company.

Dissemination

3.157. ANDRADE, J. (1993). Consciousness: Current views. In J.G. Jones (Ed.), Depth of Anesthesia: International Anesthesiology Clinics, Vol. 31 (pp. 13-25). Boston: Little, Brown and Co.

3.158. ANDRADE, J. & BADDELEY, A.D. (1993). Human memory and anaesthesia. In J.G. Jones (Ed.), Depth of Anesthesia: International Anesthesiology Clinics, 31 (pp. 39-51). Boston: Little, Brown and Co.

3.159. BADDELEY, A.D. (1990). Acoustic memory and language. Current Contents, 20, 24.

3.160. BADDELEY, A.D. (1990). The MRC Applied Psychology Unit. MRC News, June 1990, Issue No. 47, 14-17.

3.161. BADDELEY, A.D. (1993). Theories of normal memory. In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the

Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European Concerted Action (pp. 93-97). Tübingen: Gunter Narr Verlag.

3.162. BADDELEY, A.D. (1993). Verbal and visual subsystems of working memory. Current Biology, 3, 563-565.

3.163. BADDELEY, A.D. (1994). Les memoires humaines. La Recherche, 25, 730-735.

3.164. BADDELEY, A.D. (1994). Memory. In A.M. Colman (Ed.), Companion Encyclopedia of Psychology, Vol. 1 (pp. 281-301). London: Routledge.

3.165. BADDELEY, A.D. (in press). The psychology of memory. In A. D. Baddeley, B. A. Wilson, & F. N. Watts (Eds.), Handbook of Memory Disorders. Chichester: John Wiley.

3.166. BADDELEY, A.D. (in press). Working memory. In M. Gazzaniga (Ed.), Handbook of Cognitive Neuroscience. Cambridge, Mass: MIT Press.

3.167. BADDELEY, A.D. (in press). Working memory. In L. Squire (Ed.), The Encyclopedia of Learning and Memory. New York: Macmillan Publishing Company.

3.168. BEKERIAN, D.A. & DENNETT, J.L. (1990). To gain reliable evidence, child abuse victims need to be questioned carefully (Cambridgeshire project which looked at interviewing styles and techniques). In Community Care (Supplement Child Care), Nov. issue, p.7.

3.169. BEKERIAN, D.A. & DENNETT, J.L. (1991). Interviewing abused children. Policing, 7, 355-360.

3.170. McKenna, P. J., CLARE, L., & BADDELEY, A. D. (in press). Schizophrenia. In A. D. Baddeley, B. A. Wilson, & F. N. Watts (Eds.), Handbook of Memory Disorders. Chichester: John Wiley.

3.171. PATTERSON, K. (1991). Cognitive neuropsychology. Medical Research Council Annual Report, 1990/1991 (pp. 28-33). London: MRC.

3.172. PATTERSON, K. & Hodges, J.R. (1992). Progressive deterioration of semantic memory and language. MRC News, June, No. 55, 6-7.

3.173. SHANKS, D.R. (1991). Remembrance of things unconscious. New Scientist, 131, (No. 1783), 39-42.

3.174. SHANKS, D.R. (1993). Breaking Chomsky's rules. New Scientist, 138, (No. 1858), 26-30.

REFERENCES TO OTHER WORK

BADDELEY, A. (1968). How does acoustic similarity influence short-term memory? Quarterly Journal of Experimental Psychology, 20, 249-264.

BADDELEY, A. (1986). Working Memory. Oxford: Oxford University Press.

BARNARD, P.J. & TEASDALE, J.D. (1991). Interacting cognitive subsystems: A systemic approach to cognitive-affective interaction and change. Cognition and Emotion, 5, 1-39.

Bermùdez, J., MARCEL, A.J. & Eilan, N. (Eds.) (in press). The Body and the Self. Bradford Books: MIT Press.

Braak, H. & Braak, E. (1991). Neuropathological staging of Alzheimer-related changes. Acta Neuropathologica, 82, 239-259.

Brédart, S. (1993). Retrieval failures in face naming. Memory, 1, 351-366.

Bruce, V. & Valentine, T. (1985). Identity priming in the recognition of familiar faces. British Journal of Psychology, 76, 363-383.

Bruce, V. & Valentine, T. (1986). Semantic priming of familiar faces. Quarterly Journal of Experimental

Psychology, 38A, 125-150.

Bruce, V. & YOUNG, A. (1986). Understanding face recognition. British Journal of Psychology, 77, 305-327.

Burgess, N. & Hitch, G., (1992). Towards a network model of the articulatory loop. Journal of Memory and Language, 31, 429-460.

Burton, A.M. (in press). Learning new faces in an interactive activation and competition model. Visual Cognition.

Burton, A.M. & Bruce, V. (1993). Naming faces and naming names: exploring an interactive activation model of person recognition. Memory, 1, 457-480.

Burton, A.M., Bruce, V. & Johnston, R.A. (1990). Understanding face recognition with an interactive activation model. British Journal of Psychology, 81, 361-380.

Burton, A.M., YOUNG, A.W., Bruce, V., Johnston, R. & Ellis, A.W. (1991). Understanding covert recognition. Cognition, 39, 129-166.

de Haan, E.H.F., YOUNG, A. & Newcombe, F. (1987). Face recognition without awareness. Cognitive Neuropsychology, 4, 385-415.

de Haan, E.H.F., YOUNG, A.W. & Newcombe, F. (1991a). Covert and overt recognition in prosopagnosia. Brain, 114, 2575-2591.

de Haan, E.H.F., YOUNG, A.W. & Newcombe, F. (1991b). A dissociation between the sense of familiarity and access to semantic information concerning familiar people. European Journal of Cognitive Psychology, 3, 51-67.

De Renzi, E., Faglioni, P., Grossi, D. & Nichelli, P. (1991). Apperceptive and associative forms of prosopagnosia. Cortex, 27, 213-221.

Ellis, A.W. (1992). Cognitive mechanisms of face processing. Philosophical Transactions of the Royal Society, London, B335, 113-119.

Ellis, A.W., YOUNG, A.W. & Critchley, E.M.R. (1989). Loss of memory for people following temporal lobe damage. Brain, 112, 1469-1483.

Flude, B.M., Ellis, A.W. & Kay, J. (1989). Face processing and name retrieval in an anomic aphasic: names are stored separately from semantic information about familiar people. Brain and Cognition, 11, 60-72.

Funnell, E. (1993). Breakdown of object concepts and the organisation of semantic memory. Paper resented to the Experimental Psychology Society, Cambridge, July 1993.

Hanley, J.R., Pearson, N. & YOUNG, A.W. (1990). Impaired memory for new visual forms. Brain, 113, 1131-1148.

Hanley, J.R., YOUNG, A.W. & Pearson, N. (1989). Defective recognition of familiar people. Cognitive Neuropsychology, 6, 179-210.

Hanley, J.R., YOUNG, A.W. & Pearson, N. (1991). Impairment of the visuo-spatial sketch pad. Quarterly Journal of Experimental Psychology, 43A, 101-125.

Hay, D.C., YOUNG, A.W. & Ellis, A.W. (1991). Routes through the face recognition system. Quarterly Journal of Experimental Psychology, 43A, 761-791.

Hodges, J.R. (1993). Pick's disease. In A. Burns & R. Levy (Eds.), Dementia. London: Chapman and Hall.

Hodges, J.R., Salmon, D.P. & Butters, N. (1992). Semantic memory impairment in Alzheimer's disease: Failure

of access or degraded knowledge? Neuropsychologia, 30, 301-314.
Humphreys, G.W., Troscianko, T., Riddoch, M.J., Boucart, M., Donnelly, N. & Harding, G.F.A. (1992). Covert processing in different visual recognition systems. In A.D. Milner & M.D. Rugg (Eds.), The Neuropsychology of Consciousness (pp. 39-68). London: Academic Press.
Kopelman, M.D., WILSON, B.A. & BADDELEY, A.D. (1989). The autobiographical memory interview: A new assessment of autobiographical and personal semantic memory in amnesic patients. Journal of Clinical and Experimental Neuropsychology, 11, 724-744.
Lamming, M. & Newman, W. (1992). Activity-based information retrieval: Technology in support of personal memory. In F.H. Vogt (Ed.), Information Processing '92: Proceedings of the 12th World Computer Congress , Vol. III. (pp. 68-81). Amsterdam: Elsevier Science Publishers.
Levine, D.N. & Calvanio, R. (1989). Prosopagnosia: A defect in visual configural processing. Brain and Cognition, 10, 149-170.
Mandler, J. (1990). Recall of events by preverbal children. In A. Diamond (Ed.), The Development and Neural Bases of Higher Cognitive Functions. New York: New York Academy of Science.
Mandler, J., Bauer, P.J. & McDonough, L. (1991). Separating the sheep from the goats: Differentiating global categories. Cognitive Psychology, 23, 263-298.
Marr, D. (1982). Vision. San Francisco: Freeman.
MAYLOR, E.A. (1990a). Age and prospective memory. Quarterly Journal of Experimental Psychology, 42A, 471-493.
MAYLOR, E.A. (1990b). Age, blocking and the tip of the tongue state. British Journal of Psychology, 81, 123-134.
MAYLOR, E.A. (1990c). Recognizing and naming faces: Aging, memory retrieval and the tip of the tongue state. Journal of Gerontology: Psychological Sciences, 45, 215-226.
MAYLOR, E.A. (1991). Recognizing and naming tunes: Memory impairment in the elderly. Journal of Gerontology: Psychological Sciences, 46, 207-217.
MAYLOR, E.A. (1993). Minimized prospective memory loss in old age. In J. Cerella, J. Rybash, W. Hoyer & M.L. Commons (Eds.), Adult Information Processing: Limits on Loss (pp. 529-551). San Diego: Academic Press.
MAYLOR, E.A. & Rabbitt, P.M.A. (1993). Alcohol, reaction time and memory: A meta-analysis. British Journal of Psychology, 84, 301-317.
MAYLOR, E.A., Rabbitt, P.M.A., James, G.H. & Kerr, S.A. (1992). Effects of alcohol, practice and task complexity on reaction time distributions. Quarterly Journal of Experimental Psychology, 44A, 119-139.
MAYLOR, E.A. & Valentine, T. (1992). Linear and nonlinear effects of aging on categorizing and naming faces. Psychology and Aging, 7, 317-323.
McCarthy, R. (1994). Semantic quadrants: Evidence for multiple knowledge bases. Paper presented to the British Neuropsychological Society, London, March 1994.
McClelland, J.L. & Rumelhart, D.E. (1988). Explorations in Parallel Distributed Processing. Cambridge, Massachusetts: Bradford Books.
McNeil, J.E. & Warrington, E.K. (1991). Prosopagnosia: A reclassification. Quarterly Journal of Experimental

Psychology, 43A, 267-287.
Morrison, C.M., Ellis, A.W. & Quinlan, P.T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. Memory and Cognition, 20, 705-714.
MURRE, J.M.J. (1992). Categorisation and Learning in Modular Neural Networks. Hemel Hempstead: Harvester Wheatsheaf. Co-published by Lawrence Erlbaum in the USA and Canada (Hillsdale, NJ).
Rabbitt, P.M.A. & MAYLOR, E.A. (1991). Investigating models of human performance. British Journal of Psychology, 82, 259-290.
Rapp, B.A. & Caramazza, A. (1993). On the distinction between deficits of access and deficits of storage: A question of theory. Cognitive Neuropsychology, 10, 113-141.
Ross, E.D. (1980). Sensory-specific and fractional disorders of recent memory in man, 1. Isolated loss of visual recent memory. Archives of Neurology, 37, 193-200.
Schacter, D.L. (1987). Implicit memory: history and current status. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13, 501-518.
SHALLICE, T. (1988). From Neuropsychology to Mental Structure. Cambridge: Cambridge University Press.
Schneider, W. & Detweiler, M. (1987). A connectionist/control architecture for working memory. In G.H. Bower (Ed.), The Psychology of Learning and Motivation, Vol. 21. New York: Academic Press.
Snowden, J.S., Neary, D., Mann, D.M.A., Goulding, P.J. & Testa, H.J. (1992). Progressive language disorder due to lobar atrophy. Annals of Neurology, 31, 174-183.
Tranel, D. & Damasio, A.R. (1985). Knowledge without awareness: An autonomic index of facial recognition by prosopagnosics. Science, 228, 1453-1454.
Valentine, T., Moore, V., Flude, B.M., YOUNG, A.W. & Ellis, A.W. (1993). Repetition priming and proper name processing. Do common names and proper names prime each other? Memory, 1, 329-349.
Warrington, E.K. (1984). Recognition Memory Test. Windsor: NFER-Nelson.
YOUNG, A.W. (1992). Face recognition impairments. Philosophical Transactions of the Royal Society, London, B335, 47-54.
YOUNG, A.W. (1993). Recognising friends and acquaintances. In G.M. Davies & R.H. Logie (Eds.), Memory in Everyday Life (pp. 325-350). Amsterdam: North Holland.
YOUNG, A.W. (1994a). Conscious and nonconscious recognition of familiar faces. In C. Umiltà & M. Moscovitch (Eds.), Attention and Performance, XV: Conscious and Nonconscious Information Processing (pp. 153-178). Cambridge, Massachusetts: MIT Press/Bradford Books.
YOUNG, A.W. (1994b). Face recognition. In G. d'Ydewalle, P. Eelen and P. Bertelson (Eds.), International Perspectives on Psychological Science, volume 2: The State of the Art (pp. 1-27). Hove, East Sussex: Lawrence Erlbaum.
YOUNG, A.W. (1994c). Neuropsychology of awareness. In A. Revonsuo & M. Kamppinen (Eds.), Consciousness in Philosophy and Cognitive Neuroscience (pp. 173-203). Hillsdale, New Jersey: Lawrence Erlbaum.
YOUNG, A.W. & Bruce, V. (1991). Perceptual categories and the computation of 'grandmother'. European Journal of Cognitive Psychology, 3, 5-49.
YOUNG, A.W. & de Haan, E.H.F. (1992). Face recognition and awareness after brain injury. In A.D. Milner &

M.D. Rugg (Eds.), The Neuropsychology of Consciousness (pp. 69-90). London: Academic Press.

YOUNG, A.W., Hay, D.C. & Ellis, A.W. (1985). The faces that launched a thousand slips: Everyday difficulties and errors in recognizing people. British Journal of Psychology, 76, 495-523.

Collaborations

Baddeley

UK based

Della Sala - Psychology, Aberdeen

Gathercole - Psychology, Bristol

Hodges - Neurology, Cambridge

Jones - Anaesthetics, Cambridge

Logie - Psychology, Aberdeen

McKenna - Psychiatry, Cambridge

Morris - Institute of Psychiatry, London

Nicolson - Psychology, Sheffield

Robbins - Psychology, Cambridge

Outside UK

Becker - Psychiatry, Pittsburgh

McGregor - Nutrition, U West Indies

Papagno - Neurology, Milan

Salamé - Psychiatry, Strasbourg

Spinnler - Neurology, Milan

White - Psychology, Otago

Bekerian

UK based

Eldridge - Rank Xerox, Cambridge

Dritschel - Psychology, University of East London

Clifford, Toplis - Psychology, University of East London

Davies - Psychology, Leicester

Outside UK

Shaw - Psychology, Georgetown College, Kentucky

McCubbin - Psychology, Kentucky

Jackson - NISCALE, The Netherlands

Undeutsch - Psychology, Köln

Foa - Psychology, Pennsylvania

Maylor

UK based

Conway - Psychology, Bristol

Rabbit - Psychology, Manchester

Ellis - Psychology, Reading

Murre

UK based

Broeder - Psychology, Tilburg

Outside UK

Happel, Heemskerk, Hudson - Psychology, Leiden

K Patterson

UK based

Hodges - Neurology, Cambridge

A Young

UK based

Humphreys, Riddoch, Psychology, Birmingham

Newcombe - Psychology, Oxford

Ellis - Psychology, York

Flude - Psychology, Lancaster

Calder - Psychology, Durham

Outside UK

de Haan - Psychology, Utrecht

LANGUAGE AND COMMUNICATION

Bishop 3.0, Cutler 4.16, T Green 5.0 , Marslen-Wilson 0.92, McQueen 3.0, Nimmo-Smith 0.75, Norris 3.0, K Patterson 4.0, Sellen 0.73, Stark 2.25, Sturdy 3.0, Wright 5.0, Arblaster (HSO) 0.25, Blumenthal (HSO) 1.08, Borning (CO) 0.84, Bright (SO) 0.37, Butterfield (HSO)1.92, Doubleday (SO) 0.34, Duff (SO) 1.0, Hendry (SO)1.83, Hoffner (HSO) 0.5, Lickorish (HSO) 2.5, Milroy (HSO) 1.0, van Ooyen (SO) 2.67, Stacey (SO) 0.42, Strain (HSO) 2.08, Stratfold (SO) 0.17.

Total Person Years: Scientists 35.0; Research Support 17.0

Abstract

Objectives

The Language and Communication Programme combines both theoretical and applied studies aimed at (a) specifying the nature of mental representations of spoken and written language through experiments on normal adults and by computer modelling of psycholinguistic processes; (b) using studies of acquired and developmental language disorders to throw light on the interrelationships between components of language and to identify the neurological basis of such disorders; (c) identifying cognitive and environmental factors that influence people's ability to communicate effectively using a range of natural and technological devices.

Scientific progress and achievements over the past five years

A large part of the work in this programme involves experimental studies of normal adults carrying out psycholinguistic tasks under different conditions, in order to test theoretical predictions and to evaluate the contribution of different psychological processes to communicative behaviour. It is a strength of the programme that it incorporates work on all levels of communicative functioning, ranging from elementary processes of speech perception, through to studies on pragmatics and factors influencing effectiveness of communication in real-life settings. There is interest in both spoken and written language, with most of the scientists in the programme working in both areas. There is a particular focus on specifying the separability of different components of processing, and also on the extent to which there may be trade-off effects both within the domain of language and between language and other domains of cognition. This work on normal performance has both theoretical and applied importance. First, it provides a crucial baseline against which to compare the performance of (i) speakers of other languages; (ii) individuals with acquired or developmental language disorders, and (iii) computer simulations of language processes. These comparisons enable us to learn about the underlying processes involved in communicative functioning, the extent to which they depend on experience with a specific language or are universal, and whether or not they are organised in a modular fashion. Second, it provides an empirically-based rationale for those who are concerned with devising new types of information structure and novel means of communication, and ensuring that people make effective use of those communicative systems that already exist.

Specific scientific achievements

1. Provided the first experimental evidence that spoken word recognition involves inhibition between multiple, simultaneously active lexical candidates, and that the activation of competing candidates is modulated by the rhythmic characteristics of the language.
2. Illuminated, through studies of patients with semantic dementia, the way in which phonological information is stored for speech production and how this interacts with word meaning.
3. Demonstrated a major genetic influence on the aetiology of developmental language disorders, and showed that where two twins are affected with a disorder, they are remarkably similar in the pattern of language impairment.
4. Developed effective "cognitive prostheses" for users of computer-based documents.
5. Developed a formal notation to specify the key structural properties of different types of information structure, enabling progress in the development of systems which can minimize cognitive requirements such as the need to keep track of subgoals.

Future plans for the next five years

Cross-linguistic comparisons provide a powerful means of testing the generality of theories concerning the crucial underlying nature of language processing, and studies of this kind will be continued in the fields of speech perception and written language processing. In addition, we will continue to develop both computational models of psycholinguistic processes and theoretical notations for describing naturalistic information structures. These methods not only provide the discipline of requiring precise specification of the nature of psycholinguistic processes; they also, as has already been demonstrated in studies of both normal and abnormal functioning, generate new insights and lead to novel predictions to guide further experimentation. The connectionist approach to modelling generates a number of testable predictions about the developmental course of normal and disordered language development. The biological basis of language will be investigated both by further genetic studies of developmental language disorders and by functional brain imaging studies in adults. The relationships between language and nonverbal processing will be examined in both neuropsychological and applied contexts. A major theme for future work in the programme is the extent to which 'separate' cognitive processes interact, in the course of development and in on-line communicative behaviour. Both in applied work and in studies of disorders, there is considerable interest in the question of why people sometimes fail to make use of knowledge that they have, and in the role of competing cognitive demands on behaviour. We will consider how both normal and disordered language users vary in their communicative skill when either a secondary task, or the design of a naturalistic communicative device, leads to competition for cognitive resources.

Implications for improving health, health care and wealth creation

There are potentially vast commercial and practical implications of computerised systems that could carry out on-line decoding of spoken or written language. The design of such systems has, however, been limited by inadequate understanding of how humans carry out these operations. Likewise, designers of artefacts such as new computing languages or interactional software often fail to take into account the limitations of the human user; enormous costs can arise from the development of inefficient and inappropriate systems. By specifying what these limitations are and by devising analytical tools that can be applied in a wide range of contexts, we pave the way for a more rational basis for future developments. Work in this programme, where model development is guided by and tested against empirical findings, is of considerable importance for progress in this field.

Work on acquired and developmental language disorders provides a clearer conceptualisation of the causes and nature of these impairments, so that we can give more realistic information about prognosis, devise interventions directed towards amelioration of or compensation for specific deficits, and evaluate the efficacy of specific treatments.

Written information plays a central role in health care. Groups such as the Plain English Campaign stress that poor written communication can lead not just to inefficiency but also accidents. Exhortation to "try harder" is seldom enough; in order to know how/what to write, we must understand what factors create problems for readers and writers. The importance of this aspect of the programme is evidenced by the wide-ranging interest from bodies such as the British Standards Institute.

SPEECH AND LANGUAGE *(Butterfield, Cutler, McQueen, Norris)*

Introduction

Natural speech contains few reliable cues to the location of word boundaries. Indeed, the largest 'gaps' in speech occur within the words (actually within phonemes) rather than between the words themselves. This presents listeners with a problem that has no parallel in written language: How can we identify the words without first knowing where they begin and end? This is the problem of lexical segmentation. How is it that listeners can recognise the words in continuous speech in the absence of clearly marked word boundaries?

We have tackled this problem on three fronts: empirical studies of lexical segmentation and lexical access, computational modelling of speech recognition, and cross-linguistic studies. This work has shown how lexical segmentation is achieved by competition between multiple overlapping lexical candidates. That is, words beginning at many different points are accessed and these words compete with each other to determine the optimum parsing of the input. This lexical competition process is modulated by the listener's sensitivity to prosodic, or rhythmic, features of the language (the Metrical Segmentation Strategy (MSS) (4.22). In English the rhythmic unit is the foot. In French it is the syllable and in Japanese the mora. Sensitivity to prosodic information is a language specific feature of the recognition process -- different languages have different rhythmic characteristics and we have shown that even fluent bilinguals can only fully exploit a single Metrical Segmentation Strategy.

The success of this enterprise owes much to our work in developing a new connectionist model of speech recognition which incorporates both lexical competition and the Metrical Segmentation Strategy. For example, the effects of lexical competition depend crucially on the structure of the vocabulary of the language. Detailed experimental predictions can be derived only by using a model with a realistically sized vocabulary. The SHORTLIST model (4.54, 4.158) is the first major new computational model of spoken word recognition to appear in almost a decade and is the only model capable of performing appropriate large scale simulations. Computational work on this model has proceeded in parallel with empirical work on lexical access and segmentation. Experimental work has been guided by the predictions of the model and has acted as a source of constraint in further development of the theory.

A. Computational Modelling of Spoken Word Recognition

A1. The SHORTLIST Model (Norris): SHORTLIST (4.54, 4.158) is a new connectionist model of continuous speech recognition. In contrast to TRACE (McClelland & Elman, 1986), SHORTLIST is completely bottom-up and avoids the duplication of lexical networks which makes the architecture of TRACE so implausible. The central feature of the SHORTLIST model is that recognition involves competition between a small set of words selected on the basis of a purely bottom-up analysis of the input. Lexical segmentation occurs as a consequence of the competition between different candidates starting at different points in the input. In TRACE all words in the lexicon are permanently in competition with all other words. However, the bottom-up nature of SHORTLIST means that it can function with as few as two competitors beginning at each phoneme in the input and that it requires more than 108 times fewer inhibitory connections than TRACE. Not only does this feature of the model have good theoretical motivation but it has the practical benefit of enabling the model to work with a realistically large vocabulary. While TRACE is restricted to using dictionaries of about 1000 words comprised of a subset of the phonemes of English, with SHORTLIST we commonly perform simulations with a dictionary of over 26,000 words using the full inventory of English phonemes.

SHORTLIST builds on ideas developed in the race model of Cutler & Norris (1979) and the checking model of Norris (1986). In effect, SHORTLIST can be seen as a specification of the lexical access component required by both of these earlier models. More recently (4.95) we have also extended SHORTLIST to make it sensitive to prosodic information and to incorporate the Metrical Segmentation Strategy of Cutler and Norris (1988).

A2. Lexical Statistics (Cutler, McQueen): The behaviour of models of spoken word recognition necessarily depends on the structure of the vocabulary. Analyses of the vocabulary (lexical statistics) can therefore help determine the plausibility of different models and highlight particular problems that certain models might face. Both competition-based models like SHORTLIST and strictly sequential models like the Cohort model (Marslen-Wilson & Welsh, 1978) may encounter problems when the intended word has other words embedded within it (e.g., cam in camel). To assess the magnitude of this problem, a number of analyses were carried out on a large machine-readable dictionary using an interactive dictionary query system developed on the project (4.156). Each syllable and string of syllables within each polysyllabic word in the dictionary was checked against the dictionary. The efficiency of different lexical segmentation strategies was found to depend on the number and location of embedded words (4.113, 4.157).

For example, the efficiency of the Metrical Segmentation Strategy depends in part on the number of weak-initial words with unrelated words beginning from their first strong syllable (e.g. 'vermilion' contains 'million'). 16.5% of weak-initial content words were found to be of this type. But weak-initial content words make up only about 4% of conversational English, so it can be estimated that less than 1% of words normally encountered will be of the 'vermilion' type. The MSS is therefore well-suited to this aspect of vocabulary structure. An alternative segmentation strategy states that words are recognised in a strictly left-to-right manner, and that recognition of one word will locate that word's offset and hence the next word's onset. The success of this strategy depends on the proportion of words which are alike in their initial portions, since any words that are embedded at the onsets of longer words will have to be rejected to prevent postulation of false onsets. 57.5% of all polysyllables have at least one word embedded as their initial syllable. Left-to-right recognition is inappropriate given this feature of the English lexicon. Lexical segmentation based on competition (as in SHORTLIST) will be influenced by the proportion and location of words embedded in other words (see section B) but, unlike strictly left-to-right models, embedding will not disrupt recognition.

B. Empirical Work on Speech Recognition and Segmentation *(Norris, Cutler , McQueen, Butterfield)*

A central feature of the SHORTLIST model is that recognition takes place by means of lexical competition via lateral inhibition. McQueen, Norris & Cutler (4.47) provided the first experimental evidence that spoken word recognition can involve not only the activation of multiple lexical candidates, but competition between these candidates. A series of three experiments provided evidence of both the lexical competition mechanism proposed by SHORTLIST, and the MSS of Cutler and Norris (1988). McQueen et al. employed the same word-spotting task used by Cutler and Norris (1988). They asked subjects to spot words in spoken bisyllabic nonsense words such as /n´mEs/ and /d´mEs/ (as in 'domestic'). Both of these nonsense words contain the embedded word "mess". However, /d´mEs/ should also activate words like "domestic" and "domesticated". These words should compete with "mess" and make it harder to detect "mess" in /d´mEs/ than in /n´mEs/ where there are no such competitors. This is exactly what McQueen et al. (4.47) found.

Norris, McQueen & Cutler (4.95, 4.161) have extended this finding by showing that competition effects are a function of the number of active competitors. This latter study also demonstrates that there is an interaction between lexical competition and the MSS of Cutler and Norris such that the effects of the MSS are apparent only when there is a large number of competitors beginning at the onset of the strong syllable. A new version of SHORTLIST incorporates the MSS by boosting the activation of candidates beginning at the onset of strong syllables and inhibiting candidates which have strong syllable onsets where none is present in the input. The revised model gives a detailed account of these and earlier results.

The Metrical Segmentation Strategy depends crucially on listeners' ability to distinguish between strong and weak syllables. Listeners could in principle base this distinction either on prosody -- strong syllables are stressed, i.e., are longer, louder and have greater pitch movement than weak syllables -- or on vowel quality -- strong syllables have full vowels, weak syllables have reduced vowels. Results by Cutler and Butterfield (4.18) suggest that the latter distinction, vowel quality, is what listeners use. They examined the crucial case of unstressed but unreduced syllables (as in the first syllable of "condition"). In a rating task, listeners grouped these syllables together with stressed syllables (with which they share vowel quality but not stress) and distinct from reduced syllables (with which they share lack of stress, but not vowel quality).

C. Modularity in Spoken Word Recognition *(Norris, McQueen)*

A continuing theme of our research has been a concern with issues of modularity and interaction in spoken word recognition. Can spoken word recognition be explained by simple, bottom-up models, or do we need to make provision for more complex interactive theories in which, for example, information at the word level can influence decisions at the phoneme level?

Currently, the strongest evidence against a modular account of phonemic processing in lexical access comes from an elegant study by Elman and McClelland (1989). Two lines of research suggest, however, that their work may not be the fatal blow to modular theories that it first appeared to be. Norris (4.125, 4.160) has shown how simple recurrent networks trained to perform phoneme identification can simulate Elman and McClelland's data even though these networks have no lexical representations and are never taught to identify words. Essentially these networks learn to use preceding phonemic context (i.e., information within the phoneme level rather than top-down information from the lexical level) to assist phoneme identification. In non-connectionist architectures, information about preceding context is typically assumed to be derived solely from lexical information. However, in connectionist learning systems where no lexical information is available, it is difficult to prevent the networks from learning to make use of preceding phonemic context. Ironically, connectionism provides the best arguments for modularity !

A series of experimental studies by McQueen also strengthen the case for modularity. McQueen's PhD work (4.180) examined the way in which lexical knowledge influences decisions about speech sounds. Lexical involvement was measured in two tasks (rhyme monitoring and phonetic categorisation) and the predictions of two models of speech perception were compared. An interactive model, which claims that lexical effects in these tasks result from top-down flow of information from lexical to prelexical levels of processing, was contrasted with an autonomous model, which claims that lexical knowledge cannot influence prelexical processing, and that lexical effects are due to a race between lexical and prelexical phonetic decision procedures.

There were robust lexical effects in the rhyme task: word responses were reliably faster than nonword responses, and there was a significant word frequency effect (4.46). The interactive model predicts that lexical knowledge should influence rhyme decisions to nonwords as well as words, due to the presence of rhyming lexical neighbours; however, consistent lexical effects were only found on words. These experiments also showed that there is a strong strategic component in rhyme decision. In phonetic categorisation lexical effects were highly variable (McQueen, 1989). In particular, lexical involvement depended on stimulus quality. A lexical shift in the categorisation of word-final fricatives was found only after degradation by low-pass filtering (4.45). The reaction time data for this lexical effect supported the predictions of the autonomous model, but not those of the interactive model. One categorisation experiment, however, where lexical involvement was measured in a perceptual compensation for coarticulation process, yielded results which were more supportive of the interactive model. But work performed subsequently has shown (a) that the compensation result can be explained by autonomous models (4.125, 4.160) and (b) that the effect has a postperceptual component. McQueen's thesis concluded that the results in both tasks were more consistent with the autonomous race model. Further, it was argued that lexical effects in phonetic decision-making depend upon stimulus and task parameters, and that an attentional mechanism is necessary to explain this variability. It was also claimed that attentional processes can be more parsimoniously included in the autonomous model.

More recent simulation work helps gain a more detailed understanding of the behaviour of simple criterion-bias models such as Morton's (1979) logogen model and the checking model of Norris (1986). Rhodes, Parkin and Tremewan (1993) have shown that semantic priming influences signal detection theory measures of sensitivity in visual word recognition. Following an argument presented by Farah (1989), they suggested that this was evidence that semantic information influenced perceptual encoding, and that this represented a violation of modularity. Norris (4.55) shows that, contrary to Farah's claim, measures of sensitivity cannot be assumed to reflect the operation of perceptual encoding. Simulations of the logogen model/checking model demonstrate that modular criterion-bias models in which priming has no effect on perceptual encoding predict the same sensitivity effects which Rhodes at al. take as evidence against modularity. Once again, a proper formal understanding of simple modular models shows that they are far more powerful than first appears.

D. Cross-Linguistic Differences in Processing Speech ***(Cutler, Norris, Kearns)***

The international collaborations involved in this work have been made possible by a grant from the Human Frontier Science Program (HFSP).

The aim of psycholinguistics is not just to understand how humans process English, but how they process language in general. To this end our work has placed great emphasis on empirical and theoretical work covering a range of languages, selected because they have very different characteristics. Our previous work has shown that speech segmentation procedures are fundamentally different in French and in English (Cutler, Mehler, Norris & Segui, 1983, 1986, 1988). In both languages the primary unit of segmentation corresponds to the major rhythmic unit of the language. French has a syllabic rhythm whereas English has a stress based rhythm. Cutler, Mehler, Norris and Segui (4.22) extended these techniques to examine the behaviour of fluent French-English bilinguals in speech segmentation tasks. Even these fluent bilinguals did not simply behave like monolinguals in both of their languages. French-dominant bilinguals showed evidence of syllabic segmentation in French but no evidence of stress-based segmentation in English. The converse was true for English dominant bilinguals. It must be emphasised that these bilinguals appear completely fluent to native speakers of both French and English. Only by asking them which language they would least like to lose were we able to force them to express a preference for one language over another. It appears that bilinguals can develop only one of the possible rhythmically based segmentation procedures. The segmentation procedure of their dominant language is applied to all other languages.

An interesting contrast to French and English is provided by Japanese where the rhythmic unit is the mora, a unit smaller than the syllable. As predicted by our hypothesis that the rhythmic unit is also the unit of segmentation, Otake, Hatano, Cutler and Mehler (4.56) found that Japanese do indeed employ a mora-based segmentation procedure. English and French listeners presented with the Japanese speech materials responded quite differently, suggesting that mora-based processing is specific to Japanese listeners. In fact the French listeners segmented the Japanese speech by syllables, just as they segment French and English by syllables! Moraic segmentation in Japanese was confirmed in subsequent phoneme-monitoring experiments by Cutler and Otake (4.23). Japanese listeners detected phoneme targets faster when they corresponded to single-phoneme morae (e.g. /n/ in "kanji") than when they corresponded to part of a larger mora (e.g. /n/ in "kana"). Presented with English words, Japanese listeners detected /n/ faster in, for example, "cancel" than in "canopy", suggesting that they were applying their native moraic segmentation strategy to input in a foreign language. This finding therefore added further support to the evidence from the earlier studies with French listeners, who had been shown to apply syllabic segmentation to input in English and in Japanese. All of these results confirm the predictions of the Metrical Segmentation Strategy which claims that the primary unit of segmentation should be the rhythmic unit of the language.

E. Computational Modelling of Reading *(Norris)*

Norris (4.52) has developed an interactive-activation model of reading aloud. In contrast to other models, this theory gives a detailed quantitative account of both the speed and the accuracy of word naming. The model uses an interactive activation network to combine knowledge of spelling-to-sound correspondences at the levels of words, syllables, rhymes, consonant-vowel units and phonemes. As with the SHORTLIST model, interactive activation is used only to simulate the competition process within a single level of analysis; there is no interactoon between levels. The network simulates reaction-time by the number of network cycles required to exceed the response criterion. Derived from the multiple-levels approach of Shallice, Warrington and McCarthy (1983), this simple model out-performs both the Seidenberg and McClelland (1991) and the Coltheart, Atkins, Curtis and Haller (1993) models in terms of its ability to generalise to nonwords. Additionally, it successfully simulates reaction time and error data from a wide range of experimental studies of speeded word naming, showing effects of word-frequency, regularity and consistency. There are many parallels between this model and the connectionist model studied by K Patterson (see her section of this programme). Whereas Patterson's work has been directed mainly towards accounting for patterns of disordered reading following neurological impairment, Norris' model has concentrated on providing a detailed quantitative account of normal performance.

Perhaps one of the most interesting aspects of the model is that, depending on one's perspective, it can equally well be seen as a single-route, dual-route or analogy theory. Although word naming is performed by a single network (suggesting a single route), the network takes input from distinct sources of lexical and sublexical information (suggesting two routes). The sub-lexical information can however be considered as deriving from lexical representations, in line with the analogy theory of Marcel (1980). This work therefore undermines the usefulness of the central theoretical distinctions which have motivated much of the work in this area. Theoretical distinctions derived from loosely formulated verbal theories appear illusory when applied to explicit computational theories.

FUTURE RESEARCH AND TECHNOLOGY TRANSFER

A. Computational Modelling

A1. Development of SHORTLIST: Much of the work planned for the next few years is based on further study of the lexical segmentation problem. Further developments of the SHORTLIST model will provide the theoretical driving force behind this work. The general form of this research will consist of a series of empirical studies combined with simulation work. Although SHORTLIST is a theory which itself makes a number of interesting predictions, it also provides a useful computational framework for evaluating new theoretical ideas. By integrating the different components of the theory within a single model, we can establish how those components interact and can ensure that the overall theory remains internally consistent. The current version of SHORTLIST is therefore not an end in itself but the starting point for further development of a detailed and explicit computational model of human speech recognition. The sections on "Empirical work on speech recognition and segmentation" and "Cross linguistic studies" both describe further work motivated by SHORTLIST which are likely to lead to further revision and refinement of the model.

A2. The Role of the Metrical Segmentation Strategy in Vocabulary Acquisition: Although the Metrical Segmentation Strategy (MSS) has generally been presented as a strategy for using rhythmic cues to help the mature listener segment the speech stream into words, we have also assumed that the MSS will be of value in vocabulary acquisition. Children should be able to use rhythmic information to discover the location of likely word boundaries. Jusczyk, Cutler and Redanz (4.44) have already shown that infants show a preference for listening to words which begin with a strong syllable. We intend to examine the value of the MSS for discovering word boundaries by using a simple statistical procedure which can learn to identify a proportion of the word boundaries in continuous input (Redlich, 1993) by grouping frequently occurring strings of input which have a high mutual information value. We can then investigate how the performance of this simple algorithm can be improved by providing information about the location of strong syllable onsets or syllable boundaries in general. A similar exercise can be carried out in French to investigate the value of syllabic information in identifying word boundaries.

B. Empirical Work on Speech Recognition and Segmentation

One important line of investigation inspired by the SHORTLIST model will extend our study of the role of syllabic information in lexical segmentation. This work stems in part from the observation that, under certain circumstances, SHORTLIST appears to behave rather differently from people. When subjects perform a word spotting task in which they are asked whether they can hear a word in the spoken nonsense string "wreckub" they invariably report that they hear 'wreck'. In SHORTLIST "wreck" is suppressed by "wrecker" (in Southern British English the final 'r' in wrecker is not pronounced). We believe that human listeners are under a strong constraint to parse the input so that word boundaries coincide with possible syllable boundaries. There is no possible boundary in "wreckub" after "wrecker" because /b/ alone is not a possible syllable. A number of experiments are planned which will investigate this issue in a more systematic manner. For example we can compare items like "dollf" and "dollfeep". We would expect identification of "doll" in "dollfeep" to be easier than in "dollf" because there is a possible syllable boundary in "dollfeep" but not in "dollf". A number of other studies are planned to investigate the role of phonotactic information in this process. If the basic observation proves reliable this result will be interesting for a number of reasons. First, largely as a result of our own work (e.g. 4.22), syllabic information is generally considered to play a less important role in the perception of English than in the perception of languages like French which have a syllabic rhythm. This conclusion is however based on tasks requiring metalinguistic judgements about syllables. In the word spotting task, we can infer the effects of syllabic knowledge from its impact on the difficulty of word identification without requiring subjects to make metalinguistic judgements at the syllabic level. In this task we will therefore be able to compare the use of syllabic information in English and French. We will also be able to employ the same task in Japanese and compare the role of the syllable and the mora in lexical segmentation by contrasting the effects of possible syllable boundaries with possible moraic boundaries. Questions raised by the SHORTLIST model are now providing the driving force behind our cross-linguistic work as well as our work on English word recognition.

From a theoretical standpoint these studies are important because they will shed light on how listeners ensure that their interpretation of an utterance does not leave part of the input unassigned to words. In automatic speech recognition systems this is generally achieved by comparing all possible lexical parsings of the input and reducing the weighting of any parsing which leaves parts of the input unaccounted for. However, such a strategy requires that the entire utterance is considered as a whole and can generate an enormous number of possible parses which must be compared. SHORTLIST, supplemented with a strategic bias against candidates not ending at possible syllable boundaries, can perform a similar function while only considering a handful of alternative local interpretations. In SHORTLIST any unaccounted for sections of the input will always correspond to complete syllables.

C. Modularity in Spoken Word Recognition

Other work derived from the SHORTLIST model involves comparing the predictions of SHORTLIST with those of highly interactive models like TRACE (McClelland & Elman, 1986). For example TRACE accounts for both lexical and phonotactic effects in phoneme identification by the same top-down connections from the lexical to the phoneme nodes. Input which violates phonotactic constraints is harder to process than phonotactically acceptable input because it receives less top-down feedback from the lexical level. Lexical effects and phonotactic effects should therefore always be present together. In SHORTLIST, on the other hand, these two effects are independent. Phonotactic effects are purely a product of information within the phonemic level, whereas lexical effects are due to the availability of phonemic information at the lexical level. According to

SHORTLIST we should be able to demonstrate phonotactic effects in phoneme identification which remain constant even when the magnitude of lexical effects is manipulated. According to our own previous research (Cutler, Mehler, Norris & Segui, 1987) it should be possible to manipulate lexical effects by altering the composition of filler items in a phoneme monitoring or phoneme categorisation experiment. When experimental lists contain predominantly monosyllabic nonsense words, lexical effects should be greatly reduced while phonotactic effects remain . If such a manipulation can eliminate lexical effects while preserving phonotactic effects this would provide strong evidence for the bottom up account of phoneme recognition embodied in SHORTLIST and against the top-down account of phonotactic effects given by TRACE.

D. Cross Linguistic Studies

Cross-linguistic studies will continue to be an important component of work in speech recognition. SHORTLIST will be extended to include French and Dutch vocabularies to enable us to simulate a broader range of data. The experimental studies of the role of the syllable in segmentation described under B will include work on French and possibly Japanese as well as English. As mentioned above under A, computational studies of the Metrical Segmentation Strategy will include investigations of the value of syllabic information in acquisition of lexical knowledge in both English and French. This area of work will be strengthened by the appointment of Kearns whose work will concentrate primarily on cross linguistic studies.

SEMANTIC, PHONOLOGICAL AND ORTHOGRAPHIC REPRESENTATIONS OF WORDS *(K Patterson)*

Summary

The goal of this research is to explore the nature of orthographic, phonological and semantic representations of words, and to understand how these domain-specific representations interact in normal language abilities such as producing names of objects and actions (which is a computation from semantics ∅ phonology), reading words aloud (orthography ∅ phonology), reading silently for comprehension (orthography ∅ semantics), writing a spoken word (phonology ∅ orthography), etc. The principal form of evidence comes from studies of adult neurological patients who were normal language users prior to the onset of brain disease or injury: the patterns of breakdown provide insights to the premorbid organisation of language abilities. These neuropsychological studies are however accompanied by experiments with normal adults, to achieve converging evidence from impaired and normal performance. The principal techniques employed are behavioural experiments involving picture naming, word comprehension, repetition, reading and writing. These behavioural studies are however accompanied by two additional techniques, again to achieve a broader base of evidence: (a) functional brain imaging studies (PET), both of patients -- to observe regions of abnormal brain metabolism, and of normal individuals -- to determine regions of significant brain activation when the subjects are performing specific language tasks; (b) connectionist or neural-net modelling, to attempt simulation of significant aspects of human language behaviour. The principal language studied is, of course, English; the studies on normal and impaired English speakers are however accompanied by experiments with native speakers and readers of Japanese, to distinguish between aspects of our conclusions that are universal and those that are determined by the characteristics of particular languages and writing systems.

A major change in this line of research occurred when Dr J R Hodges moved to the Neurology Department in Cambridge in 1990. Prior to this, work on acquired language deficits at the APU had focussed on patients with cerebrovascular accidents (for example, 4.64, 4.128). Hodges' primary research interest is neurodegenerative diseases; and since 1990, we have been collaborating on studies of Dementia of the Alzheimer Type (DAT) and also of more focal progressive conditions (particularly progressive fluent aphasia or "semantic dementia" and progressive nonfluent aphasia) which disrupt specific components of language and memory. Due to the selective nature of the deficits, studies of progressive aphasia are ideally suited to the theoretical goals described above (exploring the interactions between semantic, phonological and orthographic domains of language representations).

A. Speech Production in Reading and Related Tasks

A1. Semantic Dementia: Semantic dementia has only recently been identified as a specific syndrome (see Warrington, 1975, and Schwartz, Marin & Saffran, 1979, for initial reports of such cases, though not with this sobriquet). We have defined the core features of semantic dementia as follows (4.41): (a) selective impairment of semantic memory, causing severe anomia, impaired single-word comprehension (both spoken and written) and an impoverished fund of general knowledge; (b) relative sparing of other components of speech production, notably syntax and phonology; (c) unimpaired perceptual skills and non-verbal problem solving abilities; (d) relatively preserved day-to-day (episodic) memory; and (e) a disorder of reading known as surface dyslexia (Marshall & Newcombe, 1973).

Given the long-standing interest and expertise at the APU in acquired disorders of reading, the surface dyslexic pattern of reading in semantic dementia has been a natural focus of research. In reading aloud, surface dyslexic patients frequently 'regularise' exception words (e.g. pint is given the more typical pronunciation of _int words in English, as in mint, lint, print, etc). Although this pattern had been reported in other patients with impaired comprehension, we were the first to argue that an intact semantic system is critical for reading of words with an atypical spelling-sound correspondence. We have expanded on this relationship in several ways, demonstrating for example (a) that the severity of surface dyslexia is significantly predicted by the degree of semantic loss (4.62), and (b) that those exception words yielding errors in comprehension tasks (like matching spoken words to pictures) are specifically more prone to misreadings (4.28).

Our next important step was to measure performance by patients with semantic dementia in repeating sequences of 3-4 words; some sequences were composed of words whose meanings the patient still appeared to know, others of words whose meanings had become degraded for that patient. By most theories, immediate repetition is a task that -- like reading aloud, only more so -- requires no semantic involvement. We observed, however, a marked difference in performance on the two types of sequence, with repetition of the now "unknown" words characterised by frequent errors, particularly transpositions of phonological elements -- e.g. the spoken sequence mint, rug repeated back as "rint, mug" (4.61).

On the basis of this pattern of results, we have hypothesised that a word's phonological representation for speech production, which almost certainly consists of linked elements rather than a whole preassembled package, derives a major part of its coherence from interaction with the word's meaning. When meaning deteriorates, this source of 'glue' is lost; the componential structure of the phonological representation is then revealed in repetition errors (mint, rug ∅ "rint, mug"), and in reading errors (pint read aloud to rhyme with "mint") which reflect typical spelling-sound correspondences of word components. A regular word can be read correctly without assistance from meaning because its pronunciation is the sum of its component parts.

A2. DAT: Patients with DAT are also germane to this line of investigation: although they have multiple cognitive deficits including a very prominent loss of day-to-day episodic memory (as would be predicted from the location and extent of brain regions affected; see K Patterson's section in the Memory Programme), deterioration of semantic memory typically becomes a significant feature as the disease progresses. We therefore predicted that reading of lower-frequency exception words should be impaired in DAT, and that the degree of this deficit should correlate with performance on tests of semantic memory. These predictions were confirmed in a group study of 45 patients classified as minimal, mild or moderate DAT (4.60). This finding conflicts with the prevailing belief that reading processes are relatively immune to DAT, and has important theoretical and clinical implications for the common use of the National Adult Reading Test (NART) as a measure of premorbid IQ in dementia.

A3. Normal Reading. Our hypothesis about the importance of communication between meaning and phonology in reading makes the prediction, not foreseen by any other theory, that word meaning should play a role in normal subjects' oral reading specifically for lower-frequency exception words. A recent series of experiments supports this hypothesis (4.97): both the accuracy and the speed of reading single words aloud reveal an interaction between regularity of spelling-sound correspondence and imageability, a semantic variable reflecting the extent to which a word's meaning has sensory properties. In sets of lower-frequency words, abstract exception words (e.g., scarce) were named aloud more slowly than either imageable exception words (soot) or abstract regular words (scribe). Perhaps even more dramatically, the normal skilled readers produced a significant number of regularisation errors only on the abstract exception words. We argue that, because of powerful statistical regularities in the relationship between orthography and phonology, only commonly encountered exception words have a major impact on setting the 'weights' on connections between orthography and phonology; less common exceptions to the rule rely on other parts of the system to assist in settling on the correct pronunciation. Words with imageable referents, in particular, are assisted by communication with semantic memory.

A4. Connectionist Modelling: Thus far, the connectionist modelling work (taking place mainly at Carnegie-Mellon University in Pittsburgh (Prof J McClelland and Dr D Plaut) and at University of Southern California (Prof M Seidenberg)) that forms part of this specific project has centred on building an adequate working simulation of the computation from orthography to phonology, using a back-propagation learning algorithm and a training vocabulary of about 3000 monosyllabic English words (4.58; Plaut & McClelland, 1993; Seidenberg & McClelland, 1989). There are clear parallels between this modelling enterprise and that of Dennis Norris (4.52), but also certain differences of emphasis. Norris' goal has been to simulate detailed (mainly reaction time) characteristics of normal readers' performance in oral reading, whereas this project is designed more to capture patterns of acquired disorders of reading, and also to develop a model of the translation from orthography to phonology that can be combined into a larger framework including semantic representations.

Until semantic representations are implemented, we cannot directly simulate our data on either the impact of word meaning in normal reading or the loss of meaning in semantic dementia. The current model is nevertheless germane to these findings in the following sense. With extensive training, the network can learn to produce correct pronunciations for essentially all trained words, even the low-frequency exception words that -- according to our hypothesis and our data from both normal and impaired readers -- require interaction with semantic representations. "Damage" to this fully trained network does not mimic the pattern of surface dyslexia in semantic dementia especially well, capturing neither the precise form of the frequency-by-regularity interaction nor the predominance of regularisation errors. A good simulation of the patient data is, however, achieved if training is stopped at a somewhat earlier stage. This suggests the following hypothesis: as a child learns to read, the weights on connections from developing orthographic representations to already established phonological representations are adjusted to capture (a) the regularities of spelling-sound correspondences, and (b) very common exceptions to these regularities (words like have and done). As the reading vocabulary grows exponentially, although the single orthography Ø phonology network probably could (as demonstrated by extensively trained simulations) learn to deal with the complexities of the whole vocabulary, there is no need for it to do so; other parts of the system, in particular connections from word meaning to both orthographic and phonological representations, can boost weak or inconsistent computations of phonology from orthography. We therefore suggest that the similar surface dyslexic reading performance observed in the incompletely trained orthography Ø phonology simulation and in our patients with semantic dementia both represent reading in the absence of the normal interaction with word meaning.

B. Reading Comprehension and Cross-Language Studies

B1. Single-Word Comprehension in Reading: Another strand of this research concerns the extent to which an adult reader's comprehension of a written word relies on activation of its phonological representation. This perennial but unsettled issue gained a new lease of life in the late 1980's, with a series of studies by Van Orden (e.g. 1987) using a yes/no semantic categorisation task (e.g., is the following word the name of an animal?). Despite knowing the correct spelling of animal names like deer and sheep, subjects make a significant number of categorisation errors to homophones of correct exemplars, both word (e.g., dear) and nonword (e.g., sheap) homophones. This result suggests that phonological codes play such a major role in reading comprehension that they can override conflicting orthographic information. The story, however, is not quite that simple; a recent series of experiments (4.12) demonstrates that the major factor determining the extent of the homophone effect is the orthographic similarity between the false and true homophones. Error rates to homophones of real category exemplars can indeed be strikingly high for orthographically similar words (dear/deer) or nonwords (sheap/sheep); but the error rate is substantially lower, and often not reliably higher than to non-homophonic control items, for orthographically dissimilar homophones (mayor/mare; phocks/fox). These results imply that phonological and orthographic codes interact to yield reading comprehension.

B2. English/Japanese: Our studies of normal adult Japanese readers performing similar reading tasks in Japanese Kanji, a non-alphabetic writing system derived from Chinese characters, have identified significant similarities and differences to results in English. It appears that the basic processes of reading in Japanese -- for example, the way in which orthographic and phonological codes interact to activate semantic representations of words -- hardly differ from English. Thus, for example, the pattern of homophone effects in reading comprehension, including the modulation by orthographic similarity between members of a homophone pair, is virtually identical in English and in Japanese Kanji, despite profound differences in the way that the two orthographies represent the sounds and meanings of their respective spoken languages (4.89). On the other hand, the precise nature of the orthography ∅ phonology computation does differ between these writing systems. Whilst this computation in English and other alphabetic orthographies occurs at both whole-word and sub-word levels, yielding the regularity/consistency effects described earlier, in Japanese Kanji the whole-word level largely dominates processes occurring for component characters. Results supporting this hypothesis from studies of normal readers can be found in 4.50 and 4.98; supporting results from acquired disorders of reading are presented in 4.130.

C. Semantic vs. Syntactic Language Abilities

As mentioned in the thumb-nail sketch of semantic dementia given earlier, marked deterioration of the semantic component of language seems to co-exist with a relative preservation of syntactic skills. We have documented this informally for speech production with assessments of the patients' spontaneous speech, which remains grammatically well-formed as it becomes progressively empty of content words other than very general nouns like "thing" and "piece" and general verbs like "make" and "do". We have also demonstrated syntactic preservation on one standardised test of speech comprehension (TROG, Bishop, 1983). Most dramatically, using on-line comprehension techniques developed by Tyler & Marslen-Wilson (see Tyler, 1992), we have shown that, as compared with monitoring for a specific word in a randomly ordered sequence of words, a patient with profound semantic dementia exhibited completely normal facilitation in a syntactically organised sequence but no further benefit (of the kind shown by normal listeners) in a semantically meaningful sequence (4.42).

D. Functional Brain Imaging

We have been using functional brain imaging techniques (PET) to investigate some of the neuroanatomical correlates of components of language processing. Because brain imaging studies are suited to a rather different type of scientific question, and also because this work is one component of a broader PET language research programme at the MRC Cyclotron Unit in London, the studies to date are not necessarily addressed to precisely the same issues as the behavioural experiments and the connectionist simulations described above. For example, our PET work on spoken word recognition began with a simple demonstration that, when normal subjects listen to familiar spoken words (by contrast with a tape of spoken words played backwards), peak activation occurs in the posterior, superior left temporal lobe -- almost precisely where, a century ago, Wernicke located the centre for speech recognition from results of post-mortem pathology in aphasic patients. In the same PET study (4.43), we observed peak activation for written words (by contrast with words written in 'false fonts', meaningless letter-like forms) in left middle-temporal cortex, not precisely at but near to the classical neurological localisation for written-word recognition. A more novel result comes from a study relating extent of blood-flow change to rate of presentation of spoken words. In virtually all areas of bilateral temporal cortex, bloodflow increased monotonically with an increase in the rate at which subjects heard spoken words (10, 30, 50, 70 or 90 words/minute). The one important exception to this rule was Wernicke's area, which was highly and equally activated at all rates of presentation (4.69). Differential sensitivity to rate of physical stimulation seems to be distinguishing between sensory processing (in primary auditory cortex) and more linguistic processing in the region specialised for language function.

E. Statistics of the Input to the Orthographic Representational System*(Sturdy)*

How is the visual input to a system that extracts an orthographic representation best described? Collaborations with Watt (Stirling University) attempted to answer this question by using his MIRAGE image processing system, developed at the APU. Technical problems meant that this work has mostly been carried out at Stirling. An alternative approach was developed, using low-level statistical measures extracted from the MRC Psycholinguistic Database. This approach assumes that the visual system extracts information from images only insofar as it is necessary for further processing modules; the work then goes on to explore the usefulness of low-level statistics, such as word length and mass, for disambiguating a target word input. The results indicate that a combination of low-level statistics and word frequency information is surprisingly useful for reducing the candidate set size to small numbers. This result motivated the development of a modification of perhaps the best-known connectionist model of word recognition, the Interactive Activation model of McClelland and Rumelhart. In this modification, information is input first to the word level of representation, and then subsequently to a bigram level of representation, rather than flowing up from a feature level to a letter level and then to a word level. Preliminary results are promising. This work has generated two offshoots: exploration of the MRC Psycholinguistic Database, and exploration of quantitative neuroanatomical constraints on building connectionist models.

PROPOSALS FOR FUTURE WORK

A. Speech Production in Reading and Related Tasks

A1. Semantic Dementia: One major aim in our initial studies of this disorder, reviewed above, has been to assess the status of phonological representations for speech production, using tasks such as word reading and repetition. We have also assessed written language production: all of our semantic dementia cases have been surface dysgraphic in writing as well as surface dyslexic in reading, making phonologically plausible spelling errors (e.g., "X-rays" written as ex-raise!) in both spontaneous writing and writing to dictation. Thus our hypothesis about the role of meaning in maintaining the integrity of representations for output applies to orthographic as well as phonological production. The hypothesis, however, is broader still. In a test known as "object decision" (Humphreys, Riddoch & Quinlan, 1988), a series of drawings -- some correctly drawn real objects and some chimeric combinations of parts of two real objects (e.g., the body of a sheep with the head of a dog) -- is presented to the subject who is asked to judge each drawing as real or not. Patients with semantic dementia are markedly impaired on object decision, which cannot be attributed to any peripheral impairment because, unlike DAT patients, semantic-dementia patients have unimpaired visuo-spatial abilities and perform at a normal level on tasks such as matching two photographs of the same object taken from different angles. The deficit instead suggests to us that high-level structural representations required for recognition as well as production depend on communication with meaning and are therefore impaired in tandem with loss of meaning. In the next phase of this project, we will evaluate this hypothesis with regard to representations required to recognise both spoken and written words, using tasks such as lexical decision, the language equivalent of object decision.

A2. DAT: In our current study, because patients were enrolled at various degrees of severity, we were able to perform useful cross-sectional analyses revealing, for example, a specific deficit in reading exception words and a general deficit in writing that is more pronounced for words with atypical spellings. This is, however, a longitudinal study, and we will soon have six consecutive data points (3 years of 6-monthly test sessions) for about 30 DAT patients from which to assess longitudinal patterns of the relationship between semantic memory and a variety of language tasks: naming, reading, writing, single-word comprehension, syntactic comprehension, etc. This is an extraordinarily rich data base that will enable us to analyse both group effects and single-case patterns; these analyses will occupy a significant amount of time over the next few years. Furthermore, we are continuing to follow the subset of patients who have not deteriorated rapidly.

A3. Normal Reading: We have just embarked on a major study to try to reproduce some significant aspects of surface dyslexia in normal readers, by one or more manipulations of the oral reading task. The manipulations include (i) mixing exception words with nonwords, (ii) forcing the subjects to name exception words at a faster-than-normal rate and (iii) altering the orthographic form of the presented words (e.g., pINT) in a way that may cause the reader to compute pronunciations of segments rather than whole words. The aim is to use evidence from normal readers to help select amongst several competing hypotheses about the nature of the deficit in surface dyslexia and, more generally, to understand the operation of the orthography ∅ phonology computation.

A4. Connectionist Modelling: As indicated above, most of the modelling work thus far has been carried out by our connectionist colleagues in America. We plan to contribute to this aspect of the work over the next few years, initially by doing various tests with the current form of the single implemented procedure (the orthography ∅ phonology network developed by Plaut & McClelland, 1993) and subsequently by helping to develop the fuller system including a semantic component.

A5. Nonfluent Progressive Aphasia: One of the major new lines of research planned for the next 5-year period will be disorders of speech production. The first main focus concerns patients with a disorder known as nonfluent progressive aphasia (or primary progressive aphasia). These patients, in whom the semantic component of language remains relatively intact in the face of severe deterioration of both phonology and syntax, are in some sense the mirror image of patients with fluent progressive aphasia or semantic dementia. We are just starting to investigate detailed aspects of speech production in several patients with this syndrome (Karen Croot, a new research student, will be concentrating on this topic for her thesis research). In the first study, the patients repeat words, read words and name pictures corresponding to the identical set of items. If the disorder is located at the stage of phonological output representations, then the rate of success and the types of errors should be largely independent of language task. If, on the other hand, the deficit involves some more central stage of language processing, then qualitative and/or quantitative aspects of performance should differ across tasks. Our preliminary results from this experiment are not only theoretically revealing but actually ground-breaking, as previous studies of this disorder have provided clinical observations but no experimental data (4.166).

A6. Progressive Anomia: The second focus of our interest in disorders of speech production has been motivated by a longitudinal study of a patient (FM) whom we originally assumed to be at an early stage of semantic dementia, but whose subsequent deterioration has shown a very different pattern. Although her initial performance on our semantic tests was not quite normal, this mild impairment has remained quite stable over a 3-year period, in sharp contrast to a profound decline in any task requiring speech production (naming, category fluency, etc). FM's immediate repetition of words is unimpaired, but she 'loses' the phonological word form rapidly: if required to count aloud for 5 seconds after hearing a spoken word, she can then correctly produce the target word on only about 50% of trials, whereas normal speakers are 100% correct after the same filled delay. Furthermore, it appears that she has a major disconnection between meaning and phonology. For example, in a gating task -- where the subject hears cumulative 50 msec chunks of a spoken word and must try to identify and produce the word -- FM receives no facilitation in the point at which she can produce the target word by seeing a picture of the object whose name she is concurrently hearing (this research is part of Kim Graham's thesis, being completed in 1994). We shall be using data of this kind to evaluate models of speech production, particularly the nature of the link between word meaning and phonological representations.

A7. Progressive Dysgraphia: One of our more striking observations in semantic dementia has been that, in addition to the surface dysgraphia seen in all cases, a subset of patients progressively lose knowledge of how to form letters and sometimes even numbers. The few published cases of such 'apraxic agraphia' have been due to CVA, where it is often difficult to establish the patient's degree of pre-morbid writing skill. In our progressive cases, where production of letter forms was intact at the beginning of the longitudinal study, we have a unique opportunity to study the deterioration of this knowledge and the status of associated abilities.

B. Reading Comprehension and Cross-Language Studies

B1. Single-Word Comprehension in Reading: Following on from the studies reviewed above, we shall continue our investigations of the relative contributions of phonological and orthographic codes in activating meaning for single words. Theorists proposing the primacy of phonology often rely heavily on one result in the literature, Van Orden's (1987) finding that, under conditions of visual masking, the homophone effect in semantic categorisation was no longer modulated by orthographic similarity: normal readers apparently accepted many false homophones followed immediately by a visual pattern mask, even if these were visually dissimilar to the correct word (e.g., "is it a number?" ATE (rather than EIGHT)). Our first attempt to replicate this result, using improved stimulus materials, yielded instead the outcome typical of unmasked semantic categorisation: a high error rate only for orthographically similar homophones. If this orthographic effect obtains in our further planned masking studies, using not only semantic categorisation but also primed word reading, it will provide critical evidence that normal reading comprehension standardly involves orthographic as well as phonological access to meaning.

B2. English/Japanese: My involvement in the project comparing normal reading in English, Japanese and Chinese (with Professor Brian Butterworth, Dr T Wydell and Dr W Yin, University College London) is drawing to a close. I have however planned cross-language neuropsychological studies, to be initiated during a 2-month period as a visiting researcher in Japan in autumn 1994. The first part of this work will focus on Japanese patients with progressive "Gogi" (word-meaning) aphasia, which -- from their neuroanatomical and behavioural pattern -- is almost certainly identical to semantic dementia. Based on our current view of similarities and differences between Japanese and English orthography and phonology, there are some clear predictions about word reading and repetition performance of Japanese patients with this disorder; and Dr Tanabe (Osaka) has kindly agreed to allow me to test several of his cases. The second part will be a broader project comparing disorders of speech production in Japanese and English (in collaboration with Drs I Tatsumi and S Sasanuma of the Tokyo Metropolitan Institute of Gerontology, my host institution in Japan). The most prominent unit of Japanese phonology is the mora (consisting typically of a consonant-plus-vowel, e.g., /ka/), and we predict that mora units will not come apart in speech production errors in the way that English syllables break up into onsets and rimes (cf the repetition errors of our semantic dementia patients discussed earlier, e.g., mint rug ∅ "rint mug").

C. Semantic vs. Syntactic Language Abilities

The separability of semantic and syntactic components of language is highly controversial. Progressive fluent and nonfluent aphasia appear to provide prima-facie evidence of a double dissociation; but like many such apparent dissociations, it will probably turn out not to be so simple. For example, although the fluent (semantic dementia) patients continue to produce largely well-formed phrases as the semantic content of their speech output deteriorates, their phrases often develop a rather steroptyped character which may not reflect full productive syntax. On the other side of the coin, the nonfluent patients may retain good comprehension of single nouns; but full understanding of verbs requires control of argument structure, and may therefore be abnormal for these syntactically impaired patients. A hypothesis to be explored over the next 5 years, for which we have preliminary support, is that, while syntactic competence may be somewhat separable from individual word meaning, it is inextricably linked to phonological abilities.

D. Functional Brain Imaging

The original motivation for embarking on this line of work was to address questions about patients with brain lesions, in particular a persistent issue regarding the role of intact right-hemisphere structures in the residual language capacities of patients with widespread left-hemisphere infarcts. The PET technology of 5 years ago was not, however, geared to the single-case analyses required for such patients. With currently improved levels of sensitivity such that, for a given permissable radioactive dose, significantly more observations can be obtained from a single subject, we are now in a position to do what we originally hoped to do 5 years ago. The broad goal is to assess the hypothesis that, in the normal population of right-handers with left-hemisphere language specialisation, there is a considerable range of right-hemisphere language capacity. Although there is currently little direct evidence for this hypothesis, it seems the most plausible explanation of the substantial variability in expressive and receptive language abilities amongst patients with large left-hemisphere lesions, and also in reading ability amongst pure alexic patients with more restricted left-occipital lesions. To address this hypothesis properly, we (Drs Richard Wise and Cathy Price at the MRC Cyclotron Unit; Dr David Howard at Birkbeck College; and K Patterson) will need to perform PET activation studies with a variety of language tasks in normal adults, pure alexic patients, globally aphasic patients and patients with left-hemisphere lesions roughly similar to the global aphasics but with markedly better post-CVA language abilities.

SPECIFIC LANGUAGE IMPAIRMENT: NATURE AND CAUSES *(Bishop)*

Introduction

Language development can be impaired if children have inadequate exposure to language or if they suffer from diseases which compromise the biological bases for language learning. For most children with speech and language difficulties, however, there is no obvious cause: hearing is normal, nonverbal intelligence is adequate, there is no physical or emotional disorder that can account for the language problems, and the home language environment seems unremarkable. This is known as specific language impairment (SLI) (see 4.101 for a review). Bishop's research has been concerned with specifying the nature and causes of this mysterious disorder, addressing three complementary questions: (i) what is the etiology of SLI, i.e., why do some children have this problem when others do not? (ii) how many types of SLI are there? (iii) what is the underlying cognitive basis of SLI? What is it about language that makes it so difficult for these children to learn?

A. Etiology of Specific Language Impairment

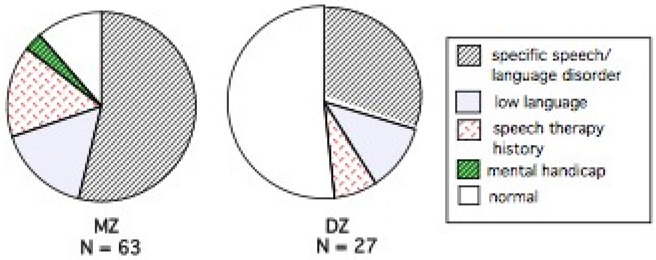
Background: For many years, etiology has remained a mystery; there is little evidence that perinatal hazard, postnatal brain damage, recurrent middle ear disease or inadequate language stimulation are implicated (Bishop, 1987). More recently, there has been a surge of interest in genetic causes, for two reasons: (i) studies of related developmental disorders, notably autism and developmental reading disorders, have found strong evidence for a heritable basis; and (ii) several studies have reported an elevated risk of SLI among family members of affected children.

A1. Twin Study of SLI: The classic twin study method provides a starting point for investigating genetic influences. Monozygotic (MZ) twins are genetically identical, whereas dizygotic (DZ) twins share, on average, half their genes. By comparing concordance rates (i.e., the percentage of pairs where both twins are affected) for MZ and DZ twins, one can estimate the importance of genetic factors. More recently, analytical methods have been developed for handling quantitative twin data, such as scores on language tests (DeFries & Fulker, 1988). We designate as probands those individuals who meet diagnostic criteria for disorder; by definition, they have scores well below average on language tests, and so the expectation is that scores of their co-twins will regress to the population mean. The difference in the regression for MZ and DZ co-twins provides an index of the contribution of genetic influences to the disorder.

Both qualitative and quantitative methods have been applied to data from 90 same-sex twin pairs, selected because at least one twin met stringent diagnostic criteria for SLI. 165 twin pairs were individually assessed on a battery of language tests and a nonverbal IQ test. Those scoring below the 10th centile on at least one out of four language tests, with a z-score discrepancy of 1.33 points or more between language score and nonverbal IQ, were designated as probands (i.e. affected with SLI).

Principal results from this study are shown in Figure 1 and reported by Bishop, North & Donlan (4.10). In brief, the study provides evidence for a genetic basis for SLI. When children are categorized according to whether or not they meet diagnostic criteria for SLI, pairwise concordance is 54% for MZ twin pairs (N=63 pairs), as compared with 30% for DZ pairs (N=27 pairs). However, this categorical approach to analysis almost certainly underestimates the genetic effects. Many "unaffected" MZ twins from discordant pairs had language scores that were just as poor as those of the co-twin, but without a substantial discrepancy with nonverbal IQ (such cases were coded as "low language"). Others had a history of speech therapy, although no problems could be detected on assessment. These results suggest that the definition of the phenotype used (based on DSM-III-R criteria) is too restrictive (4.8).

Figure 1: Classification of twin pairs according to diagnosis of twin B, where twin A meets criteria for specific speech/language disorder. Hatched area depicts pairwise concordance



Application of the DeFries-Fulker regression procedure threw further light on the question of what is inherited. All four language measures showed strong heritability, with three language tests giving estimates close to 1.0. The heritability estimates have large standard errors, and so interpretation must be cautious, but the data are consistent with the notion that there is an inherited factor that depresses receptive language ability to a mild degree, but which leads to more severe effects on expressive language development.

A2. Data on Other Family Members: Information is available from parental questionnaire concerning family history of SLI. This shows that the proportion of affected relatives in this twin sample is similar to that seen in singleton samples, and substantially higher than for a comparison sample of unaffected twins recruited by similar means. This offers some reassurance that the factors leading to SLI in twins are similar to those seen in singletons.

A3. Comparisons between SLI and Control Twins: Data from parental questionnaires and medical records are currently being analysed to see whether medical problems around the time of birth or in childhood can influence SLI. This analysis involves comparisons between the SLI twin sample and a control sample of 40 unaffected twin pairs recruited by similar means. Given the strong genetic effects found in the twin analyses, one would not expect these factors to exert a major influence on presence/absence of disorder, but the possibility remains that the severity or profile of impairment might be affected. In fact, most of the results are resoundingly negative; factors such as birth weight, Apgar score (an index of the condition of the infant at birth), middle ear disease, and seizures are all unrelated to language outcome. However, one intriguing and unexpected result emerged: there was an excess of toxaemia in the mothers of twins with SLI, and this could not be accounted for in terms of correlates of toxaemia such as social class or gender. Toxaemia is a poorly understood disease of pregnancy in which there is high blood pressure, fluid retention and protein in the urine. At first glance it looks as if maternal toxaemia could influence the developing foetus. However, in many cases of toxaemia, only one of the twins developed a language disorder. The question arises as to why two twins who are both exposed to toxaemia should differ in their outcome. It is possible that toxaemia is a marker for immunological abnormalities associated with language disorder, rather than a direct risk factor.

B. Is There a Distinct Subgroup of Children with Semantic-Pragmatic Difficulties?

Background: One of the difficulties confronting anyone studying developmental language disorders is that it is unclear whether we are dealing with a single condition or a group of different disorders. The clinical manifestations of SLI can be extremely variable. Some children have problems predominantly with production of speech sounds; others make many grammatical errors but appear to understand normally; cases have been described of children with severely restricted comprehension, and others of children who speak fluently in complex sentences but who give tangential answers to questions (Bishop & Rosenbloom, 1987).

Although most specialists recognise that there is considerable variation from child to child, attempts to devise a classification of SLI have not been successful. One problem is that multivariate classification methods depend crucially on the measures entered into the analysis. Standardized tests are not sensitive to all aspects of clinical presentation; many of the features that have been described by clinicians as important for distinguishing between subtypes are difficult to elicit in a formal assessment (4.8). This is particularly true for the pattern of disorder known as "semantic-pragmatic disorder", which Rapin (1987) describes as typified by: fluent speech with adequate articulation; verbosity; comprehension difficulties for the meaning of verbal messages; tendency to interpret messages quite literally; tendency to respond to just one or two words in a sentence; perseveration; use of circumlocutions, semantic paraphasias and lack of semantic specificity; impairment in the ability to take turns and maintain a topic in discourse. None of these clinical features could be identified simply by looking at the score on an existing language test. The clinical impression is that children with this pattern of deficits are qualitatively distinct from other language-impaired children, and may have more in common with autistic children. It is however difficult to verify this impression in the absence of any objective criteria.

Bishop and Adams (1991, 1992) were able to demonstrate pragmatic impairments in experimental tasks for children showing this profile, but the division between subtypes of language-impaired children was not as clear as had been expected. However, analysis of conversational data revealed a range of problems that could be identified reliably and which distinguished subgroups. Children with the clinical features of semantic-pragmatic disorder tended to initiate topics rather than respond to the interlocutor's overtures, and they were poor at matching the content of their message to the needs of the listener. They also tended to drift off topic and sometimes gave tangential answers to questions. Bishop and Adams (1991) concluded that attempts to elicit these behaviours in experimental contexts failed because the concrete context and explicit structure of the task allowed the child to compensate for underlying problems. It is precisely in open-ended situations, when there are no clear rules to follow and no environmental props, that the pragmatic difficulties of these children become most apparent.

These studies suggested that to identify and understand semantic-pragmatic disorder, one needs to devise methods for studying abnormalities of conversational behaviour in naturalistic contexts. This methodological shift is no light undertaking. Analysis of natural language samples is time-consuming, and the lack of experimental control makes interpretation of abnormal phenomena ambiguous. Coding open-ended data poses major problems of inter-rater reliability. Unless this step is taken, however, the characterisation and measurement of pragmatic difficulties will remain elusive.

B1. Devising a Clinical Procedure for Conversational Analysis: A project to develop a clinical procedure for conversational analysis was initiated in 1990, in collaboration with Catherine Adams at Manchester University. Development of the analysis is a cyclical procedure: in order to achieve reasonable inter-rater reliability, precise coding criteria must be specified, evaluated, and then revised, in an iterative fashion. The point has now been reached where there is a coding system that captures salient aspects of conversational behaviour, and which is extensively documented in a self-teaching manual. The analysis involves coding conversations, utterance by utterance, and provides a number of summary indices including measures of conversational assertiveness and responsiveness, ability to contribute to topic development, and overt indicators of difficulties experienced by the interlocutor. The transcription conventions have been shown to have good reliability when learned by a novice working through the manual. Inter-rater agreement for coding of conversational acts and topic development is around 80%. This should be further improved in the latest version of the coding system, which has been extensively revised to give more specific guidelines in problem areas. The project has one more year to run, during which further checks on reliability will be carried out with a new research assistant who has not been involved in developing the system. Conversations have been video-recorded and transcribed for 20 language-impaired children, half of whom meet criteria for semantic-pragmatic disorder, as well as 50 control children. These data will be used to assess the validity of the system in distinguishing both between language-impaired and control children, and between subtypes of language-impaired children.

In the course of pilot work on the coding system, a small study was carried out to investigate factors influencing one particular symptom of semantic-pragmatic disorder, "verbosity". Previous work suggested that the impression of verbosity arose not so much because children said a great deal, but because they generated utterances that were initiating rather than responsive, opening up new topics, asking questions of the adult, and generally taking the lead in conversation. This is unusual behaviour in school-aged children confronted with an unfamiliar adult. Bishop, Hartley and Weir (4.9) considered how contextual factors affected conversational behaviour in such children. One possibility was that children with semantic-pragmatic disorder might take the conversational lead in order to avoid having to answer questions posed by an adult. However, just the opposite was found: when the adult adopted a less controlling style of conversation in a toy play setting, these children were even more assertive. The verbose behaviour seen in certain children thus appears to reflect a disinhibited conversational style rather than a strategic response to a taxing and stressful situation. This interpretation meshes well with recent neuropsychological accounts of autism and related conditions that propose impairments of frontal-limbic systems involved in inhibitory processing (4.6).

C. The Nature of Grammatical Impairments in Language-Impaired Children

Background: For many language-impaired children, the most striking problems are in use of grammatical morphology. There is a tendency to omit inflectional endings (such as past tense -ed) and function words such as auxiliaries. In recent years, there has been an explosion of theory and research on this topic (see Bishop, 1992), stimulated partly by linguists who have proposed that these children may lack a specific module of an innate language-learning device (e.g. Gopnik & Crago, 1991). This view has been contrasted most strongly with that of Leonard and his colleagues (e.g. Leonard et al, 1992), who have argued that perceptual limitations may impede learning of morphological rules, especially in languages where morphological endings are neither very varied nor very salient, such as English. Both these theories maintain that SLI children lack knowledge of grammatical rules. This would seem to predict, however, that children should show consistent patterns of behaviour -- either omitting inflectional endings altogether, or using them in a haphazard, unsystematic fashion, or simply using them in specific learned contexts. For instance, the child might learn that "cats" refers to a group of animals, without having any recognition of the regular relationship between cat-cats, dog-dogs, etc.

C1. Grammatical Analysis of SLI: Bishop (4.7) analysed speech samples from 12 SLI children with severe grammatical problems and found that their production of grammatical morphology did not fit any of the predicted patterns. Thus although omissions of inflections were common, children did produce morphological endings such as past tense -ed fairly frequently, and when they did so it was nearly always appropriate. Furthermore, variability in production of inflections was not word-specific: thus the same word would be produced correctly inflected in some contexts, but (wrongly) uninflected in others. This led to a search for factors that might account for the variability in performance. In fact there already exists a body of research that is relevant to this issue, although it has tended to inhabit a theoretical vacuum, unrelated to mainstream studies. This is work on "linguistic trade-offs", which has demonstrated that complexity at one level of language processing (e.g. phonology) can influence accuracy of performance at another (e.g. grammatical morphology). This line of work suggested that limited processing capacity might be affecting the ability of SLI children to carry out the operations necessary to compute and retrieve morphological endings. If so, accuracy should perhaps be affected by the complexity of the message they were attempting, and the amount of material already formulated. Tentative support for this notion was found in the corpus of data studied by Bishop (4.7). The likelihood of producing the correct morphological ending decreased with serial position of a word in the utterance.

FUTURE PROPOSALS

A. Etiology and Prognosis of SLI

A1. Twin Study: The principal aim is to home in on a clearer definition of the phenotype for SLI, and to find markers for the phenotype that will distinguish teenagers and adults with a past history of SLI from those without such history. Subsidiary aims are (i) to use genetic data to test the notion that SLI is a qualitatively distinct disorder, as opposed to simply a quantitative departure from normality; and (ii) to use twin data to test the theoretical basis for associations between language disorder, literacy problems and abnormal motor development and lateralization.

In the past few years it has been increasingly recognised that methods from behaviour genetics can answer questions that go far beyond simple estimation of heritability. Twin data can throw light on the definition of the phenotype, and on causal relationships between correlated impairments. For instance, we know that impaired motor performance is common in children with SLI: is this a manifestation of the same underlying condition, or a coincidental phenomenon? An extension of the DeFries-Fulker method enables us to see whether a common genetic factor can account for co-morbidity between two disorders. If the same genetic factors lead to both language and motor deficits, then poor language performance in the proband should predict poor motor scores in the co-twin, with the extent of impairment depending on the strength of genetic relationship. This method will be used to examine the nature of the relationship between SLI and (a) slow motor performance on a tapping task (cf. 4.68); (b) laterality on the tapping task (cf. Bishop, 1990); (c) reading and spelling disability (see Bishop & Adams, 1990a); and (d) measures of phonological short-term memory (Gathercole & Baddeley, 1990).

There are two important reasons for retesting the existing sample of twins. First, the data obtained so far point to further measures that will illuminate our understanding of the phenotype; second, by retesting children after an interval, we can assess notions about how the presentation of disorder changes with age (see 4.8).

In terms of further measures, now that a genetic basis for SLI has been demonstrated, the search is on to find the best marker for the phenotype. Collaborative work is planned with Professor Paula Tallal of Rutgers University to look at heritability of performance on a task of rapid auditory processing. Tallal has for many years argued that the linguistic manifestations of SLI are secondary to a more fundamental temporal processing deficit, such that the auditory perceptual system has limited temporal resolution and so cannot adequately process rapidly changing or brief signals. In more recent work, she has proposed a neurobiological basis for this disorder, linking it to work suggesting analogous problems in handling transient information in the visual system in reading-disabled children. Her theoretical orientation contrasts sharply with that of researchers such as Gopnik, who argue for specific syntactic deficiencies, and with hypotheses put forward by Gathercole and Baddeley (1990) and by Bishop (4.7), who suggest that SLI may be due to fundamental deficits in components of a working memory system. It will be of particular interest to devise tests which pit these hypotheses against one another.

In addition to studies of the existing twin sample, Bishop has been asked to collaborate in a new large-scale longitudinal twin study which will be carried out by Professor Robert Plomin, Professor Michael Rutter and Dr Emily Simonoff at the Institute of Psychiatry in London. This study aims to investigate the heritability of mild mental impairments, and will also provide an opportunity to use genetic data to validate the distinction between specific and global developmental disorders involving language. A large national cohort of twins will be screened starting at 2 years of age to identify those with significant developmental delays, with affected cases being subjected to more detailed investigation.

One factor emphasised by the twin study that has just been completed is the way in which the presentation of SLI can change with age. On the basis of medical and speech therapy records, it seems that many children continued to show significant improvement as they progressed into adolescence. Bishop will collaborate with Professor Maggie Snowling and Dr Carole Kaplan of Newcastle University in a follow-up of a sample of SLI children originally studied at the age of 4 years by Bishop and Edmundson (1987). The sample is now aged 15 to 16 years; by studying them we will be able to specify more closely the long-term prognosis of SLI, and document how patterns of impairment change over time.

A2. Family Studies: It is usually assumed that a single dominant gene could not be responsible for causing SLI because pedigree data do not fit a Mendelian pattern of inheritance. That was the case in the twin study, where many twins with SLI did not have an affected parent. However, caution is needed. As noted above, the presentation of SLI changes with age, and heritable forms of disorder may resolve as children grow older. In future research on SLI, we aim to study cases of "resolved SLI" to evaluate proposed markers of residual problems; these should enable us to re-define the phenotype to include cases of transient problems. Tallal is currently involved in family studies of SLI, which provide evidence that the temporal processing deficit can be demonstrated in adult relatives of SLI children, who do not have obvious indications of language difficulties. The temporal processing test is, therefore, a promising marker of the phenotype, although it is not the only one we shall be using. In general, the best candidate markers are novel tasks which subjects have not had an opportunity to practice, such as repetition, reading or writing of nonsense words.

A3. Comparisons with Control Twins: The DeFries-Fulker method of analysis provides an estimate of group heritability, i.e. the extent to which genetic factors can explain a language deficit. This may differ from conventional estimates of heritability of a trait (h2), which estimates the genetic contribution to individual differences within the normal range. If there is a single factor, such as a major gene, that depresses test scores in a minority of individuals, then these two heritability estimates could differ substantially. One may draw an analogy with height: variations in height in the normal population have moderate heritability and appear to be influenced by a wide range of genes; however, certain forms of dwarfism are caused by a single major gene that is of very rare occurrence. Thus the factors that cause severe limitations of stature are different from those that influence height in the normal range. A comparison between group heritability (i.e. role of genetic influences in causing impairment) and conventional individual heritability will help to determine whether a developmental disorder simply corresponds to the tail of the normal distribution of ability, or whether it is a qualitatitively distinct disorder with a specific etiology. The very high estimates of group heritability that we obtained for our language measures suggest that the causes of disorder are different from the causes of normal variation; but, to answer this question properly, we need to investigate heritability of the same language abilities in the normal population. To this end, a sample of twins of similar age and nonverbal ability will be recruited and given the same language assessments.

B. Experimental Studies of Children with Pragmatic Difficulties

The in-depth analysis of conversations that has been entailed by work so far has suggested a number of hypotheses about the underlying nature of pragmatic problems. These are not mutually exclusive, and there is some suggestion that different problems may predominate in different children. More systematic testing of these hypotheses will be carried out using experimental measures.

B1. Differentiating Explanations of Semantic-Pragmatic Disorder: A popular view is that pragmatic difficulties arise in children who have limitations of social cognition, akin to, but less severe than, those seen in autistic children (Bishop, 1989). Bishop and Adams (1989) noted that a common source of problems was a failure to match the message to the listener, so that a child would either tell a conversational partner something they already knew, or would fail to provide information that was crucial for understanding. Both characteristics tended to co-exist in the same child, suggesting a fundamental problem in understanding how much shared knowledge the interlocutor had. If this does reflect a problem with social interaction, we would expect to be able to demonstrate two kinds of associated impairment: (i) abnormalities of nonverbal communication (e.g. in the use of gaze) and (ii) problems with tasks that involve "theory of mind". To date, however, attempts to demonstrate such problems using experimental tasks have been largely unsuccessful; as well as the referential communication task used by Bishop and Adams (1991), there are unpublished data on a theory of mind task, and results from an undergraduate project looking at use of eye contact in conversational settings. In none of these studies have any deficits been shown in children with semantic-pragmatic disorder. This has led to the formulation of alternative explanatory hypotheses (see below). Before ruling out defective social cognition as an explanation, however, we need to see whether children who seem insensitive to the interlocutor's needs in conversation do have difficulty with more complicated tasks testing theory of mind.

A more linguistically-based hypothesis proposes that conversational problems may arise because the child uses low-frequency words and expressions without fully understanding their meaning and appropriate use. For example, Bishop and Adams (1989) described a boy who seemed to use "because" as a general purpose connective, and other children use discourse markers such as "well" and "by the way" in a haphazard fashion at inappropriate points. This gives their conversation a superficially adult appearance, but confuses the interlocutor, who, for instance, will anticipate some kind of topic shift after hearing "by the way". We will determine whether children who show this kind of behaviour have problems in judging acceptability of utterances that include these kinds of expressions in appropriate and inappropriate contexts.

One conversational feature that does not seem to be explicable in either linguistic or social terms is the tendency to drift off topic. This is an elusive problem that has been very difficult to pin down, illustrated in the following example;

adult: do you ever have parties at school?
child: no.
adult: what about at Christmas?
child: it snows.

The child's final turn has a clear link to the content of the preceding utterance, but there is no link to what may be termed the global topic that has been defined by the preceding stretch of conversation (which may be loosely characterised as "parties"). This suggests that the child has problems in building a mental model that incorporates new information into a structure containing all the salient prior information. This account has something in common with Caplan et al's (1990) proposed explanation for "loose associations" and "illogical thinking" in the connected speech of schizophrenic children who manifest frank thought disorder. They suggested that limited processing capacity and/or distractibility lead to difficulties in keeping track of topic in a conversation. Problems in inhibiting irrelevant thoughts may lead to intrusion of unrelated material into the conversation. Although these conversational features are far more severe in schizophrenia than in the language-impaired subjects studied by Bishop and colleagues, they seem qualitatitively similar, suggesting that it would be worthwhile looking more closely at attentional processes and ability to inhibit irrelevant responses in children who show this pattern. We are developing a task which is designed to assess facilitatory and inhibitory attentional effects, adapting a paradigm from mainstream experimental research on attention (including work by Duncan: see his section in the programme on Attention and Cognitive Control) to make it suitable for young subjects.

B2. A Checklist for Identifying Semantic-Pragmatic Problems: Pilot work has been done to develop a checklist, which takes 23 areas of communicative functioning which are not easily assessed by conventional methods.

Included are several symptom areas which are characteristic of semantic-pragmatic disorder, such as ability to mesh conversation with that of a partner, conversational assertiveness, nonverbal communication, prosody, and tendency to give tangential responses. For each area, a teacher choses from five descriptions the one which is most like the child. Inter-rater reliability will be assessed with the help of staff at schools for language-impaired children. If these behaviours can be measured reliably, this will provide a more solid and objective background against which to evaluate findings from conversational analysis, as well as indicating whether the symptoms of semantic-pragmatic disorder do group coherently.

B3. Application of the Conversational Analysis Procedure to Other Clinical Groups: Once we have an analytical method that is both reliable and valid in identifying pragmatic difficulties, this will be a valuable tool for investigating conversational competence in other clinical groups who have been described as having communicative problems that are not easy to quantify with existing assessments (e.g. head-injured patients with frontal lobe impairments; schizophrenic patients; individuals with fragile X syndrome or Asperger's syndrome). Informal links are already established with Dr David Skuse of the Institute of Child Health in London, who is keen to apply this method to girls with Turner's syndrome. These children have average verbal abilities, with poor visuospatial skills. Recent work has documented problems with social relationships in this population. The typical picture is of a child who presents as sociable and unusually mature in interactional style, but who has difficulties in making friends. A couple of cases seen in collaboration with Dr Skuse had oddities of communicative style when analysed in detail, particularly in terms of inappropriate use of adult-like discourse markers (see B1 above). It is predicted that conversation analysis procedure would discriminate girls with Turner's syndrome from a control group and would throw light on their social impairment.

C. Experimental Studies of Grammatical Deficits in Children and Adults

C1. Manipulating the Conditions Under Which Grammatical Errors Occur: The aim is test the notion that grammatical deficits reflect limited processing capacity by manipulating the amount of verbal and nonverbal material that has to be processed in a task, and observing the effects on the ability to produce appropriate morphological endings. If children with SLI have not learned grammatical rules, then morphological deficits should be apparent in all situations. If one can manipulate error rates, this would be evidence against a 'lack of competence' account. The principal motivation for these studies comes from previous work on children with SLI. However, similar issues arise in the study of adults with acquired aphasia, where it has been suggested that agrammatic symptoms may reflect performance limitations rather than a lack of linguistic competence (Hesketh & Bishop, 1994), and it is intended to extend this work to investigate the limited-capacity hypothesis. Similar test materials and methods would be appropriate for individuals with developmental and acquired language disorders. Subjects will be presented with sentences that have either a correctly inflected verb, or an obligatory inflection omitted, or an inflection wrongly added. The task is (i) to repeat the sentence and (ii) to make a grammaticality judgement. It is predicted that accuracy of production will decrease with serial position of the inflected item in the utterance, in line with the pattern seen in spontaneous speech data. Grammaticality judgement is often regarded as an index of "competence" rather than "performance", but it does require the subject to generate and evaluate a grammatical representation of what has been heard; it is therefore possible that, if parsing took place unusually slowly, or representations decayed very fast (see also Baddeley et al, submitted), then one would see problems similar to those observed in production, with the language analyser developing an ever-increasing backlog of material as sentence length increased. Other variables that would be predicted to influence accuracy if a performance limitation was implicated are (i) rate of presentation; (ii) inter-item interval; and (iii) word frequency of the inflected item (on the assumption that low frequency verbs would take longer to access than high frequency words). In addition, there is the question of whether any capacity limitation is restricted to language, or whether performance on this type of task could be enhanced or impaired by requring the subject to perform a secondary, nonverbal task that demanded attention (e.g. pressing a button when a light appeared).

C2. Syntactic Processing in Children with Moderate Hearing Loss: It is often argued that SLI must involve dysfunction of an innate grammatical module, because the grammatical difficulties of these children are so selective and severe. This logic is, however, faulty. A relatively peripheral auditory processing deficit could, in principal, alter the course of grammatical development in just this way (Bishop 1992). To evaluate this notion, tests of syntactic comprehension and production will be administered to children with partial hearing loss to see if similar and selective grammatical deficits can arise purely as a result of peripheral auditory deficits.

STRATEGIES FOR READING AND WRITING *(Stark, Wright)*

Introduction

One goal of this research is to understand how document design influences the strategies that people adopt when reading work-related materials or information provided for the general public. Readers draw upon a wide range of cognitive resources, including attention, comprehension and memory processes. They also plan actions and monitor their execution (e.g. in order to follow written instructions). A premise underlying this research is that we need to know what strategic activities readers engage in when working with written materials, and whether these activities are helpful or not, before we discover how writers can best support readers through judicious information design. The scientific issue concerns how these diverse cognitive activities are integrated by readers.

People are often economical in their reading behaviour, choosing not to attend to information on the page in front of them. The influence of pictures on such attentional strategies is unclear because most research on pictures in text has examined the effects on comprehension and memory. We have explored the attentional effects of including two kinds of pictures in documents: diagrams offering an overview of the text and line drawings referring to textual details. By controlling when readers encountered pictures during reading we have been able to investigate the cognitive consequences of over-ruling the reader's chosen strategy, and so could assess the benefits of encouraging readers to adopt different ways of integrating text and graphics.

Written instructions pervade both working and private life yet they are often presented in a way that makes them difficult to follow. Some of the reasons for poor instructions are organisational, others lie in the cognitive processes of written communication. A second goal of our research is to understand the cognitive processes of creating written communications. It is known that writers may not appreciate the information needs of their audience, but it is unclear whether this blindspot is restricted to certain kinds of content. We have extended this research in two directions, examining writers' choices about both content and presentation. By manipulating the potential for referential errors in the environment where the instructions would be carried out, we were able to explore writers' presuppositions about readers' knowledge. We also compared readers' preference for words or pictures with writers' choice of representational form when giving route directions. A difference between these choices implies that inexperienced instruction-givers do not consider the full range of design options when writing.

Currently most of the research being done on information design focuses on human-computer interaction. In contrast, many of our studies address issues relating to the strategies people use for reading printed materials. We exploit electronic documents as a convenient research tool and benefit from the advantage that the research can also address design issues relating to the use of computer-based documents. There is a practical need for this. An international survey showed that researchers in the behavioural sciences are increasingly doing part of their work at home, enabled by information technology (4.77). We have therefore examined reading strategies with the new kinds of document structures and the additional forms of reader-support that are possible for computer-based documents (4.85, 4.137).

A. Strategies of Attending when Texts have Pictures*(Wright, Lickorish, Milroy)*

A1. Attending to Graphic Overviews: The two main issues addressed in this series of experiments were (a) Did people separate or integrate the reading of text and graphics? (b) Did the strategy adopted enhance or impair comprehension and retention? The text was presented on a computer screen and readers only needed to click with the mouse on a label on the screen to access the graphic, which was a verbally labelled box diagram. Most people studied the graphic before and/or after but not during their reading of the text, suggesting that they anticipated cognitive costs from accessing the graphic overview. However, repeating the graphic throughout the text rather than leaving it to be accessed by choice helped readers incorporate the information from the graphic while building the gist of the text, and resulted in better scores on a subsequent quiz. This finding calls into question an explanation of readers' strategies being the result of the cognitive costs of integrating text and graphics. This lack of cost was also found when graphics were interspersed through the text summarising the information up to that point: study time was reduced but quiz scores were still high. In order to check whether reluctance to study the full overview diagram was caused by the amount of detail it contained , the gradually growing graphic was made available to readers, but they still seldom accessed it as an organising aid while reading (4.81). When the text was accessed from the diagram, instead of the other way around, we found that reading times and quiz scores were almost as good (4.175). These studies show that readers' understanding can be improved if they integrate information from a graphic overview while building the gist of a text, but that people may not have the appropriate control/access strategies for doing this (4.174).

A2. Attending to Graphic Definitions: We examined readers' strategies for attending to glossary information while reading. It was hypothesized that people's willingness to interupt their reading would be influenced by the way the explanation was signalled within and accessed from the text (e.g. either implicit or perceptually cued) and also by the representational form (verbal/pictorial) of the explanation (4.11). People read through several texts in which they could click on any unfamiliar words and have the meaning appear in the margin in a form that was either entirely verbal or verbal+pictorial. We found that readers' meta-understanding was a crucial determinant of their access strategy. Implicit cues were adequate for novel words but not for partially known words, where salient flagging of the clickable items significantly increased the frequency with which readers accessed the explanations. The inclusion of graphics had no significant effects, but when the explanation included a line drawing this led to more re-reading of the text, suggesting that comprehension processes associated with higher levels of discourse processing may have been hampered by the inclusion of the picture. Studies are under way to extend this work to animated graphics (see proposals for future work). Although readers could maintain their fixation on the text when verbal definitions were presented auditorily, this too resulted in more re-reading of the text. It is concluded that there are cognitive costs associated with requiring readers to integrate across the modality of representation (words/pictures) and across the sensory modality of input (visual/auditory). These findings motivate the reading strategy people adopted for the studies reported in A1. Since most graphics will amplify details rather than provide overviews, readers may over-generalise a single strategy for integrating text and graphics.

A3. Providing Diagrams: Given that readers do not attend to graphics while reading, it is plausible that neither do writers while writing. This series of experiments examined whether non-professional writers would add graphics to text, and if they did, whether these would be as overviews or as details (4.88). The task was to explain to a stranger how to cross the writer's home town on foot. It was found that these authors rarely included a diagram of the route to be taken, whether writing a letter to a friend or drafting a design for the back page of a leaflet. Yet these authors could draw route diagrams and always included a diagram when assembling the message from preformed elements. Route instructions that included sketch maps were rated as more usable than instructions without graphics; yet even after doing this rating task, people continued to write instructions without including sketch maps. These data show that the knowledge people have as readers is not necessarily accessed when they write. It is suggested that this particular writing task may be speech driven, with the writers imagining themselves talking to a stranger.

B. Search Strategies and Memory when Problem Solving *(Wright, Lickorish, Milroy, Stark)*

B1. Memory Demands in Find and Compare Tasks: When readers need to compare details in different parts of a document, they must remember both where to go and what they have already found. Providing readers with optional memory aids is an unobtrusive way of assessing the differential memory demands within such tasks. This research was prompted by our discovery that in a find-and-compare task, readers' choice of procedure for moving around a document varied with the content and/or organizational structure of the text (4.84). In a series of experiments designed to clarify the determinants of readers' navigation choices, we examined the adequacy of five models which differed in predicting whether readers would select the procedure having: (i) the fewest actions, (ii) the smallest memory demands, (iii) the greatest ease of learning, (iv) the simplest overall heuristic, (v) the fastest cognitive computation times. In our first study the best predictions of navigation strategy for various search tasks came from the cognitive computation times (an analysis first proposed by Card, Moran and Newell, 1983). When the navigation procedure that had been chosen most often was modified, the analysis of cognitive computation times predicted readers would choose an alternative navigation procedure, but they did not. Encouraging readers to use the rejected navigation procedure showed that it gave faster solution times and did so without increasing use of the retrospective memory aids. Across this series of experiments the use of memory aids was strongly predicted by the length of the navigation procedure chosen (4.85). That is to say, search strategies determined memory demands, not the other way round. Further studies showed that people's navigation choices were strongly influenced by perceptual factors (4.86). This series of studies has seen the development of a powerful new paradigm for exploring readers' meta-memory, through the use of on-line memory aids. Our data suggest differences between retrospective and prospective memory in this kind of reading task. This research also raises issues about the kinds of cognitive support that can, and need to, be provided for people working with computer-based documents (4.137). Wright has summarised the support readers need when undertaking different kinds of search tasks within documents (4.133) and has overviewed the design implications arising from the cognitive demands of readers needing to move from place to place within electronic texts (4.138).

B2. Memory and Rhetorical Assignments within Non-Linear Texts: When people are reading texts in which additional verbal information can be summoned into view, this additional information may be accorded the status of an aside or it may gain salience from the act of summoning it. Stark showed that when people were searching texts for items having a specified combination of target features, this separation of the information sources improved readers' memory for the material, compared with leaving all details in the main text. Far from subordinating the information, the use of a pop-up window seemed to add emphasis (4.74), although readers' performance was disrupted if the summoned information occluded the main text (4.75). Several of the general design issues surrounding the use of non-linear documents have been discussed (4.136, 4.170, 4.172). Stark has provided a detailed analysis of the computer-based tools that can assist problem solvers when faced with taking decisions in multi-attribute contexts (4.132).

B3. Impact of Computers on Creativity and Problem Solving: For people inexperienced in using computers, the requirement to work with computer-based information may be analogous to imposing a secondary task. While this may only slow down routine activities, it may seriously hamper creative problem solving. This has implications for documentation as writers increasingly keyboard their own materials instead of passing manuscripts to typists. Wright examined the effects on creativity when students of architecture undertook a five-day design project working with computers and also by traditional means. No decrement was found for the computer-based system although the pattern of work changed and students worked in longer stretches when using the computer. The data pointed to some prerequisite skills for success in computer-aided design. Students with high scores on a copy-drawing task and on a spatial thinking task gained high marks for their computer designs (4.129, 4.167). This suggests that the basic cognitive skills needed for creative 3-D design are not changed by shifting the design medium.

C. Following and Giving Directions *(Wright, Lickorish)*

C1. Avoiding Ambiguity in Verbal Instructions: The findings from our previous research on instructions have been applied to computer documentation (4.134) and to the design of instructions for the general public (4.139). We have carried out a new series of experiments exploring writers' choices about sequencing information and their awareness of the need for increasing precision when giving instructions in contexts where the potential for ambiguity is varied (4.80). People were asked to write instructions for modifying a typescript. It was found that few writers provided an overview and many left readers to do a considerable amount of problem solving to work out where the instructions should be applied. When the typescript was modified so that the potential for ambiguity was increased, writers responded by framing their instructions more precisely but many still remained ambiguous. Writers' choices about sequencing information have theoretical significance relating to the integration of different cognitive processes. It was found that most writers first mentioned the general location (e.g. the second paragraph), then the action to be performed (underline Tuesday), and then gave the precise location where the action was to be carried out (e.g. on the third line). This ordering reflects a compromise between supporting comprehension through a canonical declarative word order, and helping readers formulate a procedural action plan for which the reverse order is needed. It is concluded that giving verbal instructions is a linguistic skill that not all adults have perfected; and writers easily make faulty presuppositions about their readers .

C2. Wayfinding Inside Buildings: People often have difficulties locating destinations within modern building complexes such as hospitals. Because sign-posting needs to answer readers' questions, a survey was undertaken to discover what destinations people were looking for when entering the outpatients department in a local hospital. It was found that one third were looking for a place defined by a person's name (e.g. Mr Smith's clinic), one third were looking for a place defined by medical treatment (e.g. eye clinic) and one third were looking for an architecturally defined place (e.g. room G12). This heterogeneity made signposting in the hospital more difficult than it need be. The problem could be reduced by making one of these categories much more salient in the letter of appointment (4.87).

Signposting within a building can be supported by hand-held maps generated from office desktop publishing facilities. In order to examine the relevance of such maps to a hospital outpatients' department, we devised an experimental procedure with similarities to a Treasure Hunt. It was found essential to modify the first map we produced because of misinterpretations by readers (4.87). This supports the view that empirical evaluation is an essential component of information design. Comparison of people navigating with and without the map showed that map users did not double back on their tracks so often, which suggests they were less often lost. However, they did not reach their destinations any faster because they took time to plan their route; and this they considered to be time well spent (4.82). These findings urge caution in assuming that fastest performance is best where information design is concerned. There is a need for greater understanding of how readers interact with written materials and the value people place on being able to use the information in the ways that they want.

D. Translating Research into Practitioner Domains *(Wright)*

One indication of the impact of this research on practical issues is the range of occasions during the past five years when we have been asked to relate research findings to specific practitioner domains (e.g. that of the professional technical writer - 4.187). Requests from academic groups outside psychology have resulted in keynote conference papers on the topic of quality in documentation (for the Canadian Centre for Research in the Writing Process (4.135) and the Applied Linguistics Department at the University of Twente in Holland (4.140)); and on instructions for the public (for the Design Engineering Department of the University of Delft - 4.139). Papers on information design were requested by professional groups such as the Printing Industry Research Association (4.169, 4.189). The Association for Clinical Research in the Pharmaceutical Industry invited a chapter on the design of Case Report Forms (4.83). In addition several workshops were held for professional communicators (e.g. University Computer Support Services; clinical researchers, etc). Membership of committees convened by the British Standards Institute has offered another means of bridging the gap between laboratory and practice. Substantial contributions have been made to seven British Standards relating to documentation. Also several papers have been republished in edited books; this too helps to disseminate the research beyond the boundaries of academe (Wright, 1977; 1986; 1988).

FUTURE PROPOSALS

Overview

A major problem in understanding reading and writing strategies is in knowing which psychological processes will be the major determinants of performance such as following instructions or taking decisions. Our work on the influence of design factors on readers' behaviour has shown that predicting the interplay among processes such as attention, comprehension and memory requires situating the cognition within the task constraints and the affordances of the information environment. Our proposed research will maintain its focus on the three subdomains of (a) texts with graphics, (b) documents that are searched and (c) material conveying procedural instructions. Within each subdomain, however, the theoretical focus will be shifted by changing the task demands. For texts having graphics the shift will be towards comprehension and memory processes. Although this is a major focus within the research literature, new issues arise concerning the strategic trade-offs readers make between access and comprehension processes when the adjunct materials (whether verbal or pictorial) are animated.

Readers engage in many kinds of search but the few models of document searching that currently exist are concerned with students extracting information from expository text. We propose to examine the relevance of these models to adults filtering information in order to take decisions about multidimensional problems. One of the key issues is the extent to which the order in which searchers consider the various attributes introduces biases into their decision-making. A related issue is whether features of the interface, such as the availability of data-marking and data-collecting tools, can change search strategies.

The theme of reading and writing instructions will build on our previous work but will focus on how readers create action plans. One issue to be addressed is whether readers create a mental representation of the actions to be performed that is independent of the symbolic form in which the instructions are given. By contrasting verbal and pictorial materials, questions about the cognitive comparability of these representations can be answered. In addition we will examine people's ability to comply with instructions on how to write, for example by following a model of the text structure required. This research could be considered an empirical contribution to the theme of translating research into practitioner domains.

A. Comprehension and Memory when Reading Graphics and Text

Background: We have already shown that, during reading, people easily integrate verbal adjuncts to a text but choose not to integrate pictorial information. We propose to explore the role of verbal/pictorial representations in determining these alternative strategies. The scientific question is whether building discourse understanding from a multimodal text has cognitive costs, and whether these comprehension costs are offset by enhanced retention of the material. It is important to extend this research to procedural information because instructions differ from narrative text in three critical respects: (a) readers can deal with the text in piecemeal fashion and may not need to construct higher level discourse representations; (b) the material read will not need to be remembered for long if the instructions are to be implemented immediately; (c) the precise details of the text are of crucial importance. Animating graphic instructions enables the dynamic features of the procedure to be shown. However, there could be disadvantages if readers' strategic options for reflection and review are constrained by the animated display. This expansion of the research will link themes A and C.

Proposal: The convergent objectives of this research will be realised in separate series of studies, each with more limited aims: (1) To ascertain whether the formation of qualitatively different mental representations is one of the causal factors underlying the reluctance of readers to integrate text and graphics while reading. (2) To determine whether the differential advantages of overviews compared with graphics of textual details will apply to animated graphics. It is hypothesised that animation will increase readers' willingness to attend to the graphics but will decrease their retention of the main text for both categories of graphic. (3) To explore how readers cope with procedural instructions given as animated graphic sequences. It is predicted that problems of readers wanting to reflect and review will arise only with longer procedural sequences.

A range of covariate measures will be taken in order to assess the comparability of the independent treatment groups and to enable post-hoc stratification of the data. The graphic adjuncts to the texts will vary in the proportion of verbal and pictorial information they contain, and across different groups will vary in amount of animation. In order to investigate the interplay among attention, comprehension and memory processes, the comparisons will be replicated with different ways of accessing the graphic materials and with graphic displays that either do or do not occlude the text. Presentation will be self-paced and people will be free to re-read the text and graphics if they wish. In all studies the main measures of performance will be (i) reading pattern - i.e. the frequency of switching between the text and the graphics, (ii) time to complete the task, (iii) time spent studying the text, (iv) time spent studying the graphic, and (v) performance on immediate and delayed retention tests. In addition, for the procedural instructions, the reading pattern will include switching between the instructions and the domain in which the instructions must be carried out, and retention will also be indexed by errors and memory lapses in carrying out the instructions.

B. Attending to Multiple Criteria when Searching

Background: Our interest in readers' search strategies has been motivated by its usefulness in highlighting some of the concurrent memory demands involved. Previously, in tasks having well-defined search targets, we examined the prospective and retrospective memory demands when several items had to be found and then compared on a single attribute; but there are many other kinds of search task. We propose to examine searches involving multiple criteria (e.g. someone looking for a GP who is in a small practice that is fairly near their home and which has ample parking space). Here people reduce the memory problems by attending to successive subsets of criteria. This can be done in several ways and different search strategies may lead to different kinds of errors. Little is known about the strategies people adopt when searching documents for multidimensional targets, nor whether their search strategies are malleable and influenced by the perceptual characteristics of the display or by whatever aids to searching are available.

There already exists evidence that people search multi-attribute arrays more rapidly if these are iconic rather than verbal, but the generality of this finding could be limited by the structure of the document. Recent work by May and Barnard has provided a model of the interaction between the features of icons and the visual structure underlying the interface of a software application (May, Barnard & Blandford, 1993; May, Barnard, Boecker & Green, 1990; May, Tweedie & Barnard, 1993). This can be extended to highly formatted text structures such as tables. Readers' search strategy may also be influenced by the document tools that they have available for highlighting items for further consideration or removing items that need not be considered further. The use of such tools relates to the design of cognitive prostheses supporting attentional and memory processes. This overlap of the areas of search and decision-making and problem solving promises to be a fruitful conjunction for highlighting the strategic control of several cognitive processes.

Proposal: One objective will be to investigate how adequately existing models of readers searching prose texts (e.g. Guthrie, 1988) will apply to people "filtering" information in order to take a multi-dimensional decision. A second objective is to determine the extent to which readers' search strategy depends on situational factors such as the symbolic representation of the search features (verbal/iconic), the document structure (table/list), or the filtering tools available.

A novel research procedure will need to be invented in which people can be presented with electronic documents containing multi-dimensional information about familiar entities, such as houses or shrubs, and be asked use this information to find the item that best meets a particular set of requirements. Special-purpose, computer-based tools will be made available to assist searchers, and will differentially assist in excluding non-contenders or highlighting potential targets. A range of covariate measures, including verbal and pictorial memory, will be taken in order to assess the comparability of the different treatment groups and to enable post-hoc stratification of the data. Search strategy will be revealed by the pattern of tool-use (i.e. whether searchers drop items out of the attended set or highlight items into this set). The speed and accuracy of solving the problems will indicate which strategies are the more efficient.

C. Following and Giving Directions

Background: Having already established that people are not very successful at giving written instructions, we propose to shift the research focus from writing processes to reading processes, or more specifically to the creation of plans for action on the basis of what has been read. Most research on verbal directions has focused on the linguistic characteristics of discrete instructions involving only one or two steps. As a consequence very little is currently known about people's reading strategies when following a lengthy sequence of instructions. Here meta-memory processes could play a crucial role, since the readers' success will depend in part on knowing how much to try to remember. Remembering too little means returning often to read the instructions; attempting to remember too much risks errors.

The need to communicate instructions across language boundaries has increased the use of pictorial instructions, but there are also issues about how easily people can remember a pictorial sequence compared with a verbal description of the same procedure. In discussing executive control functions, Barnard has pointed out that the representation adopted by learners can have a crucial effect on how the content is processed and thereby on what is learned (Lee, 1993). If readers construct a mental model of the procedure to be carried out, then alternative presentations of instructions (verbal/graphic) may influence the ease with which the model can be created, but once built there should be no residual differences in ease of retention or application. On the other hand, if people's mental representations vary with how the instructions are given, this may have a range of performance consequences for speed, accuracy, confidence, etc. There could be important differences in the mental representations people choose to create for visuo-spatial and visuo-temporal instructions. Green found that for people trying to understand the temporal contingencies represented in programming languages, visual notations similar to circuit diagrams were less helpful than verbal representations (4.36, 4.37). For visuo-spatial contingencies the reverse might be true.

There are contexts where instructions can be given by providing readers with a model of the output required rather than a detailed sequence of steps for achieving that output. Organisations that have documentation house styles often use models in this way. We propose to explore factors that may influence the ability of people to match a model of an effective communication.

Proposal: This research will have three major aims, each realised in a separate series of experiments. One aim is to ascertain whether readers are sufficiently aware of the meta memory demands of instructions to segment them into appropriate chunks when creating action plans. If it is found that readers' segmentation strategies are inappropriate, then design remedies will be sought - e.g. by providing visual segmentation cues on screen. A second objective is to establish whether, for instructions that are to be carried out immediately, a common mental representation for action plans is created irrespective of the symbolic form of the instructions (verbal/graphic). The third objective is to explore whether people can generate appropriate action plans to write in a way that follows a textual model. Models differing in their display features and in their underlying organisation will be used. We predict that, because it enhances attentional control, people will be able to follow a model more successfully when they have had the opportunity to contrast this with alternative textual models.

In order to study the issues of segmentation and representation we will develop a computer based two-window task, one window for the instructions and another for the "machine" on which the instructions must be carried out. Readers will summon the instructions step by step, switching at will between the reading and acting windows. The time spent and the activities undertaken in the reading window (e.g. requesting the next procedural step or reviewing previous steps) will indicate the segment size within action plans. Success in carrying out the instruction provides an index of readers' understanding and memory of the instructions.

The studies of the mental representations adopted for action plans will employ an interference paradigm. If readers retain many of the surface features of the instructions, then doing a verbal task such as unscrambling proverbs after reading the instructions and before carrying them out should be more harmful to verbally presented instructions than to graphic ones. Conversely a visual rotation task, such as the manikin test, should be more disruptive when instructions are pictorial rather than verbal. Appropriate control conditions will show if readers create action plans to minimise interference from the intervening task.

The studies exploring whether textual models offer a way of enhancing the quality of written directions will use written exemplars differing in their underlying structures and in their display features. People will be asked to follow these models when organising information extracted from a neutral source. In addition, people will be asked to assess the suitability of a range of models for particular audiences and purposes. These assessment data will address the issue of the relation between sensitivity as a reader and empathy as a writer. Measures of attitudes to writing and writing abilities will ensure the comparability of the different treatment groups. The dependent measures will include the closeness of the writer's style to the model and the adequacy of the details extracted from the information source.

D. Translating Research for Practitioners

There are no signs that the demand for "translation" activities will decrease. Certainly BSI activity continues. The proposed research on people's use of documentation models contributes directly to this theme.

NOTATIONAL STRUCTURES AND INFORMATION ARTIFACTS *(Green)*

Introduction

Much communication takes place in other ways than through the medium of unconstrained natural language; artificial systems, such as charts, diagrams, tables, and notations are in wide use, forming a class of 'information artifacts' whose purpose is to represent and to communicate. With the growth of computer-based technology have come artifacts which can store and manipulate information, such as personal calculators, data-bases, word processors, systems for CAD (computer-aided design), etc. As is only too obvious, there is still much to be done to help designers avoid putting unrealistic demands on users' abilities. Wealth creation can come, in this context, from improving the competitive edge of British and European design.

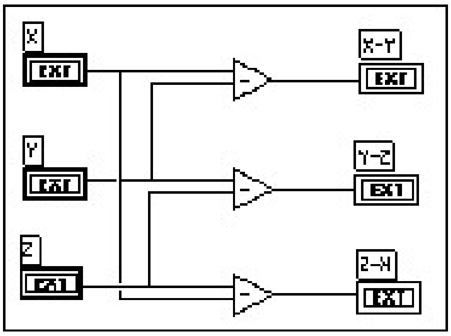
Quite apart from their immediate practical relevance, artificial systems are interesting vehicles for study because they can be refashioned (unlike natural language), because they combine linguistic and graphical elements, because they are small enough to allow formal analysis and therefore to allow experimental manipulations, and because they engage several aspects of human performance such as subgoal tracking, the perception of structure (= parsing, when the material is linguistic), and trade-off decisions between alternative strategies. To understand the determinants of behaviour, especially the trade-off decisions, it is necessary to be able to describe the cognitively meaningful properties of artifacts.

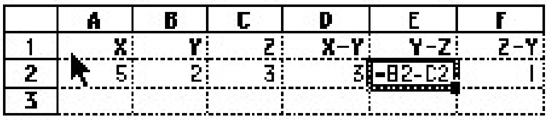
Structural features called 'cognitive dimensions of notations' are the corner¬stone of Green's approach, each dimension being one structural feature that is more or less independent of the rest. These 'dimensions' are applicable to every kind of information artifact – not just spreadsheets, but also to CAD systems, programming languages, outliners, etc. Indeed, they would also be applicable to non-interactive information structures, such as timetables, music scores, and the complex patterns of technical prose.

There are two aims to this analysis. On the theoretical side, before we can apply laboratory-based psychology to wider contexts, we need a way to relate the wider contexts to the purified tasks studied in the laboratory. The theoretical aim is therefore to develop a well-defined system of analysis that will provide metrics on, for instance, the number of subgoals that must be created in order to perform certain operations, and to use such analyses to test the applicability of psychological models. In so doing, it has become apparent that existing psychological models need to be extended to deal with the different properties of artificial systems as against natural ones (for example, parsing models need to be extended to deal with programming languages rather than natural language).

The practical aim is to provide a framework of terms that is readily comprehensible to domain specialists, so that a person who used, say, architectural design systems would quickly understand how the dimensions were to be interpreted in that domain. Ideally, these dimensions would be recognised as names for problems or concepts that had a familiar feel, even if they had not been explicitly recognised before.

It is easiest to discover the relevant 'cognitive dimensions' by comparing several different information artifacts; just focusing on a single artifact fails to reveal enough ways in which it might have been different. By way of example we contrast the familiar spreadsheet with a recent development, the box-and-wire style of 'visual program'. The dimensions have been grouped under four headings relating to reading, changing, learning, and testing the validity and usefulness of the framework as a whole.





Above, fragment of a spreadsheet, with one cell 'opened' to show the contents. Left, a box-and-wire visual program computing the same expression. Data is read from a panel (not shown) into the boxes X, Y, and Z, and it flows along 'wires' to operators and into the output boxes (X-Y, etc.), which control pictures of meters, dials, etc. on the panel.

A. Reading Notations

It is a truism of cognitive psychology that people assign structures to text, scenes, etc., and act on the perceived structure; but the realms of artificial notations (and especially mixed representations, where textual elements conspire with graphical) have been little explored. Research in this area has intrinsic interest – can a single parsing model cover such a wide span, or must we posit different cognitive processes for different notations? Research in this area also has very direct application to the development of notations and working environments. Indeed, the general problem of how structure is assigned is one of the most intriguing questions in psychology.

A1. Role Expressiveness and Structure Parsing: The first research question is how to design a notation that is 'role-expressive', i.e. easy to parse into higher-order structures.

A1.1 Parsing notations: A good model of parsing would tell us how to design for easier parsing. The particular problems of parsing visually-presented partly-graphical representations are that parsing can start anywhere, may have very long range dependencies (although usually rather simple types of dependency), has no analogue to the verb phrase, and can proceed by developing islands of structure in any convenient order. This is unlike parsing spoken natural language, the paradigm for most psycholinguistic models of parsing.

Evidence from many sources shows that programs in conventional programming languages are schematised into structures such as that shown below, which bind together several possibly-discontiguous components, and there is every reason to suppose that other notations are similarly schematised into appropriate structures.

Green and Borning (4.33) used an extended form of unification parsing to develop a model capable of parsing short programs in Pascal and Prolog into such schemas.

Sum: = 0; addup2(0, 0).

for J: = 1 to N addup2(N, A) :-

```
begin read( X ), N1 is N-1, addup2( N1, B ),
read X; A is B + X.
Sum := Sum + X
end
```

Underlined components illustrate a 'running-total' plan in Pascal (left) and Prolog.

A unification parser has many advantages as a model of parsing visually-presented material, since it is not tied to word order and since it can incorporate non-lexical information such as indenting and colour cues. Green and Borning predicted that Prolog would be harder to parse than Pascal because its syntax contains fewer keywords, delimiters, and other equivalents of closed-class morphemes. Preliminary experiments by Green and Duff confirmed these predictions: highly experienced Prolog and C programmers were shown programs in their 'native' language from which small pieces had been snipped, and were timed as they matched the excerpts with the gaps. Equivalent programs for three algorithms were used, each with three levels of complexity and with snips made at equivalent points in the semantic structure; identifiers were suppressed to avoid lexical cues, so that subjects were forced to answer by parsing for meaning. Results showed that Prolog subjects took longer and that the increase of time with complexity was greater for Prolog. Notation designers should therefore include cues to help readers identify higher-level structures.

A2. Easing the Parsing Operations: Comprehending graphics versus text: Despite the conventional wisdom that graphical notations are easy to understand, graphical representations are not necessarily better than textual ones. Green, Bellamy and Petre compared comprehensibility of compound conditional expressions in two forms of textual notation and two forms of 'box-and-wire' graphical notation, derived from LabVIEW, a commercial graphical programming language in use at the APU. Subjects in one group were familiar with LabVIEW and had at least some exposure to conventional programming languages, another group were professional users of a very similar graphical notation. Short fragments of programs were presented and subjects answered either a 'forwards' or a 'backwards' question (forwards: what will this program do if X, Y, Z are true? backwards: this program did that, which of X, Y, Z must be true?). All subjects, whatever their experience, performed faster with textual than with graphical notation. Forwards/backwards differences depended on the type of information structure, as predicted. A serious difficulty with the graphical notation is that it requires a version of perceptual maze-following, in which pointers to choice-points have to be stacked up in working memory. Alternative schemes need to be created (4.36, 4.37)

Pointer structures and comprehension: Certain artificial languages also possess 'pointer' or 'indirect' forms of reference, in which an operator is applied not directly to an object but to a second object to which the first object refers. It is widely believed that this is difficult, at least for less experienced users. Green and Baurén modelled the process in a production system language and showed experimentally that similar effects could be demonstrated in a non-programming context. Their analysis was that the over-riding problem in comprehending pointers is that one fragment of the mental representation must be rewritten twice (once to 'dereference' the pointer – i.e. look up its value – and once to dereference the pointee). Their experiment modelled pointer comprehension with a task in which subjects had to mentally replace substrings found in larger strings, following a set of rewriting rules; difficulty was exacerbated when the same fragment was rewritten twice, supporting the basic analysis. Further experiments will be needed to complete this work, but the implication is that notation designers should avoid pointer structures except for expert use. (4.142)

A3. Improving Role-expressiveness

A3.1 Understanding object hierarchies: According to Green's approach, a good notation allows easy parsing for the relevant higher-order mental structures ('role-expressiveness'). 'Object-oriented' programming systems offer an opportunity to test this hypothesis. These systems model the world as objects which interact via messages. Thus, the 'world' could contain a tiny eco-system – cat, mouse, cow, milk, grass, cheese – and messages could pass between these objects to set up a food-chain. It has been claimed that this approach has cognitive benefits over conventional programming.

Typically, however, object-oriented systems only allow the programmer to view the program according to a strict hierarchical structure, a sort of taxonomy. Although in the programmer's conception of the program, objects of one class may interact with objects of other classes to form a coherent substructure such as a food chain, there is no way to represent that conceptual structure; it has to be deduced from the individual messages. Comprehending the program as a whole is made much more difficult. One solution is to add a 'description level' allowing experienced programmers to externalise their own knowledge of a complex program, and to provide means for browsing this description. This prospect has been expounded in detail (4.35) with a cognitive rationale for the various suggestions.

Green led a 3-year JCI-funded project to create a 'Cognitive Browser' as a component of an object-oriented programming environment being constructed at UCL. For technical reasons, the UCL site was forced to modify original proposals, which made it impossible to produce a working version of the Cognitive Browser in the time available. The team nevertheless carried out in-depth studies of the implementational and architectural aspects, together with a wide variety of empirical investigations into cognitive representations of programs, the process of program design, and the utility of graphical representations of programs and of hierarchical classification structures. (Much of Green's work during the present reporting period was related to this project, but has been organised under topic headings here.)

Davies et al. showed that the object hierarchy was by no means the only determinant, often not even the major determinant, of mental structures. Blumenthal (Green's RO) showed that the form of external representation played a significant component in the elicited structure. These studies confirmed the main hypothesis, that programmers' mental representations are much richer than the code representations of the programs (4.25, 4.144).

A3.2 Role-expressiveness in spreadsheets: When it became clear that a working cognitive browser would not become available in time for experimental use, a small-scale system, 'CogMap' (cognitive mapper) was built by Hendry and Green. CogMap replicated the main functionality of the Cognitive Browser proposal in the less demanding domain of spreadsheets. Heavy spreadsheet users were recruited and requested to describe in detail the workings of an actual spreadsheet which they had constructed. All their assertions about the roles of components were successfully translated into the CogMap system, thus demonstrating the adequacy of its representational system (4.38). These interviews also revealed much about how spreadsheet programmers developed personal conventions to represent non-programming facts about their code (where different types of data came from, which parts described different aspects of the enterprise, etc.). Spreadsheet programmers evidently choose to trade-off increased role-expressiveness against increased demands on working memory to keep track of how their conventions are being applied (4.40). Similar interview studies by Green and Petre of professional electronics designers using CAD found very similar usage of personal conventions, as a form of secondary notation, showing that role-expressiveness was relevant to a very different design domain (4.65, 4.66).

B. Changing Structures

B1. A Meta-Notation to reveal Viscosity and Hidden Dependencies (Green, Benyon, Petre): Some information structures are easier to update than others. For instance, updating all the cross-references and section numbers in such a text as this can be very lengthy work. In the cognitive dimensions framework, Green calls this effort viscosity ('resistance to local change'). Differing types of viscosity, examples, and methods of treatment are described in (4.29). In a highly viscous system, one task goal may spawn many subgoals which have no direct relation to the main task. As the work of Robertson and Duncan shows, keeping track of subgoals may be a near-impossibility for some people, so knowing how to create systems which reduce or avoid them would be highly desirable.

The problem is to expose this and other structural properties in some other way than by tedious verbal descriptions, and to obtain a workable measure. By considering information structures as a specialised form of data-base, Green was able to apply a modified and extended form of entity-relationship modelling, a well-understood computer science technique. The resulting meta-notation, called entity-relationship modelling for information artefacts (ERMIA), can be used to represent many types of information structure in a single, easily-understood form, which can be displayed graphically or in symbolic form (the latter allowing manipulation by logic programming languages such as Prolog) (4.30). The resulting 'structure maps' display very clearly some of the key structural properties: how many search steps are required, how many components must be changed to achieve a given transformation (=viscosity), locations of hidden dependencies, etc.

C. Learning

C1. Consistency & Regularity: Language systems are not arbitrary collections of idiosyncratic rules; they have a degree of internal coherence, known as linguistic regularity. In the previous reporting period Green presented research on modelling the user's knowledge of consistency in simple 'action languages' such as word processors and spreadsheets using 'task-action grammar', a form of two-level grammar in which one level, the rule schema, unpacked into a collection of closely-related rules. This model was predictively successful but too complex to be theoretically convincing or practically useful.

During the present reporting period, advances in connectionist research have produced impressive models of regularity effects in developmental psycholinguistics, suggesting that similar models could be applied to the related world of artificial languages. Green and Doubleday used a very straightforward back-propagation architecture to assess regularity of an artificial language, using as a metric the number of training trials required to reach a criterion performance at which all the inputs, such as 'delete word', generated values sufficiently close to 0 or 1 at the output nodes, which were interpreted as command keys such as Control + G.

They were able to predict the results of all published experiments on regularity effects in artificial languages, except those in which the system being modelled included any substantial degree of syntactic order, for which more sophisticated architecture will need to be used. Their technique also revealed patches of local inconsistency, which could be helpful to designers.

This result raises the possibility of 'plug-in' evaluations for designs for information artifacts. Instead of requiring a specialist to construct a two-level grammar from which consistency can be determined, a simple description of the inputs and outputs could be plugged into a network and evaluated automatically. If the network took too long to learn the language, one could predict that humans would also have difficulty (4.34).

D. Validity & Usefulness

D1. Testing the Cognitive Dimensions Framework as a Whole: Questions to address are whether the framework is reasonably complete and whether it agrees with the evidence on human performance. Many sources of evidence have been pressed into service over the reporting period: conventional laboratory studies, observational studies, expert opinion, and formal analytical methods.

With regard to the issue of completeness, a particular domain of information artifacts has been studied in depth, namely the design of programming languages. Green and Petre carried out a comparative analysis of 5 such languages, contrasting various attributes (textual or graphical, 'neat' or 'scruffy', 'deep' or 'shallow'). The languages were assessed on each of the cognitive dimensions and comparisons made with all extant user studies on each language. This large project revealed both the lack of serious data regarding most usability aspects of languages and environments, and the lack of 'extensible' theory to apply; for example, parsing theories do not extend to these circumstances, and there is no unified theory of 'hard mental operations', only of special cases like self-embedding. Even in the better-researched area of program design, we could find little dealing with the role of visibility and accessibility of one part of the design while working on the next part. Nevertheless, some usable data exist, and straw tests of some dimensions, such as viscosity, were devised; results were highly encouraging, both as regards the framework as an analytical tool and as a way to communicate to non-specialists (4.92).

To be useful in practice, the framework needs to be comprehensible to domain specialists with no prior knowledge of cognitive psychology. To test this Green collaborated with Modugno, a computer scientist at Carnegie-Mellon. Independent evaluations of a visual programming environment were found to agree well, and inspired several design improvements (4.48).

D2. Knowledge Dissemination: Psychologists frequently complain that their knowledge is not used in design. In the case of software, Green's analysis of the present state of knowledge dissemination (4.118) argues that the agendas, publishing practices, and incentive structures of cognitive psychologists and software engineers differ so greatly as to make dissemination particularly difficult. A survey of recently published texts on software engineering revealed almost no penetration of cognitive psychology, although folk psychology was frequently invoked to explain decisions about the design of programming languages and programming environments. Moreover, design decisions were made in isolation, with no awareness of trade-offs and dependencies. The role of the cognitive dimensions framework is to serve as a form of 'discussion tool', allowing shared understanding between the two communities, and helping to take analysis to a deeper level than the usual list of features.

This role can only be served if the framework is widely disseminated. Green has therefore started to seek opportunities to publish in outlets that will be read by practitioners of software engineering and information design (4.31, 4.67, 4.93, 4.96).

FUTURE PROPOSALS

Green's work has exposed areas where cognitive psychology offers the opportunity to contribute in new ways, and has extended the areas of applicability of existing theory in interesting and fruitful ways. In addition it has shown that we can discern the trade-offs between different cognitive dimensions. For these reasons, the main plan for the coming five years is to extend this line of work and to formulate a unified account of principles of notational design.

Five major targets need to be attained. The metanotational analysis of structure needs to be taken forward so that each dimension can be given a formal definition, conflicts and overlap can be reduced, and where possible, metrics can be devised; areas which have received little or no attention to date need to be researched; the trade-offs between dimensions need to be studied; the framework needs to be tried out in a fresh domain; and the ideas need to be disseminated to the relevant communities.

A. Metanotational Description of Interdependencies

In the immediate future, the ERMIA project with Benyon and Petre will be taken forward, to decompose the notions of viscosity and hidden dependencies as completely as possible. The targets for the project include testing the usability of the notation by developing a teaching package and evaluating it with Open University students, comparing their between-student agreement in identifying viscosity and other structural properties.

Green is also working on applying the notation to understanding the 'emergent' properties of graphs. The classic analysis by Bertin (1981) distinguishes different levels of using a data graph, and maintains that the purpose of a graphic is to support discovering overall relationships; despite the fact that he presents many examples of redrawing graphics to present overall relationships better, however, he has no underlying theory. Structural analysis identifies the mapping relationships and the conditions that must hold in order to make overall relationships perceptible.

A very simple underlying theory is probably adequate: low-level data components must map onto graph components without 'chasm' or 'fan' traps; the graph components must meet perceptual conditions for emergent properties such as clusters; and those emergent patterns must map onto high-level data relationships. The advance is not in the theory but in the development of a description in which the graphical elements are described in the same language as the data they represent, and the perceptual conditions can be stated in the same language too.

B. Areas Needing Research

Certain parts of the framework, such as propensity to errors, have been well enough researched in other contexts to need little special effort except that of making the literature available in a compact form. Other areas need more work, and two stand out at present.

B1. Imposed Look-Ahead: Sometimes, even in quite simple cases, users need to look ahead to know what to do. The ordinary pocket calculator forces users to think ahead, to foresee the need for parentheses. On the other hand, the notation for rewriting text strings in Unix-based regular expression editors, although grisly and unreadable, has the virtue that it does not force look-ahead. Needless to say, far more complex and potentially expensive examples can be cited.

The analysis of imposed look-ahead requires understanding of both the notational structure (and its environment of use) and the user's mental representation. If these two are not congruent, the cognitive process will generate entities in a different order from that required by the notation. Gray and Anderson (1987) give a detailed analysis of the look-ahead problem for novices constructing Lisp conditionals. How serious the consequences are will depend on the degree to which the environment controls the order of actions: if, for instance, notational components must be entered in strict left-to-right order (as in the calculator), the user will have to restart expressions when components are left out; whereas in more forgiving environments, it will be possible to edit the partly-built structure. Repairing errors is a separate theme, however.

The aim of research in this area is to predict the look-ahead problem and to investigate the resources used to cope with it by practised users. The research will require usable descriptions of the notational structure, the transforms allowed by the environment, and the order constraints imposed; these are mainly analytical problems. Developing Green and Benyon's ERMIA notation will go some way to providing the structural description of the notation, but the permissible transforms and the order constraints need a different approach. Various techniques are available for eliciting mental representations; making a choice will be deferred until a domain has been chosen. Research of this type needs subjects who are experienced users of some system in a domain that can be satisfactorily analysed, but there are many possible domains where experienced users are available, including CAD design and software engineering. It is also hoped to build experimental domains in which varying degrees of lookahead are required and varying degrees of order constraint are imposed. This will require programming manpower.

B2. Role-Expressiveness: To extend parsing models into the domain of visual programming, the first step must be to investigate the cognitive representation of visual programs, about which little is known. For text-based languages a variety of methods have been used: priming, line-by-line revelation with guessing at what comes next, free search using a peephole to see in what order experts scrutinised the text, debugging with controlled cues for semantic or syntactic constructs, and inevitably recall of legal programs versus scrambled ones. Free search has high face validity for our purposes. Robertson et al. (1990) were able to segment their subjects' search traces into 'episodes' that related well to surface-level structural features within the code, usually data flow, and concluded that these corresponded to cognitive constructs at the 'program meaning' level. An alternative interpretation is that their results are a surface phenomenon, not a deep one, and that the effects are caused by the subjects' need to cope with creating links between partially hidden dependencies. (Overlooking the need to process such surface complexities bedevils cognitive psychology in various ways.) Repeating the study using visual programs will test their theory, because data flow is a perceptually manifest dependency in visual program, rather than a purely symbolic one: however, other types of surface dependency can be introduced. We would predict that relative novices will be responsive to surface dependencies, while experts will also be guided by the 'meaning' of the program in deciding which part of it to study next. A successful visual parser would model the expert's behaviour, as it built up a model of the program.

The unification-based parsing investigated by Green and Borning was on the right track, but the system developed could only handle small program fragments. A very promising line is unification-based interesting-corner parsing using a generalisation of chart parsing, such as the version developed by Mellish et al (1992). Their parser has been applied to parsing travel information, using excerpts from police road incident logs as the input material, which has much in common with the structure of a program (long range dependencies, proper names, and the need for an approximate semantic interpretation in order to locate interesting corners). However, there is no graphical element to their parser, nor have they sought to discover the determinants of ease-of-parsing.

Research in this area will proceed in collaboration with one or more experts in computational linguistics. We shall adapt an existing model for which some degree of psycholinguistic support already exists; derive testable predictions from it, applicable to mixed-medium notations; then test these predictions on experienced users.

C. Trade-Off Relationships and Performance Effects

The framework describes a number of ways in which a notation that has an undesirable position on one dimension can be improved, but at the cost of changing its position on another dimension. Unwanted viscosity can be improved by introducing more abstractions, for example, so that many low-level actions are replaced by one high-level action; but the management of abstractions creates new problems of lookahead (which abstractions will be needed?) and of hidden dependencies (what will happen if a given component is changed?). Increasing role-expressiveness can frequently increase viscosity, and so on.

If these manipulations can be shown to have the predicted trade-off effects, it will strongly support the framework. With the growth of interest in 'rational analysis', led by Anderson (1993), this will be a timely investigation, for there will be increasing interest in how cognitive costs determine behaviour.

A very useful lead has been given by O'Hara and Payne (1994, submitted) who showed that in simple tasks (Tower of Hanoi and sliding-block puzzles), users adopted more planning and less situation-based action as the effort per operation was increased. One of their manipulations corresponded closely to an increase in viscosity. Sliding-block puzzles are very restrictive, however, and the proposal is to develop environments for more open-ended tasks.

A likely area to investigate is hypertext. Hypertext systems typically have rather high viscosity, many hidden dependencies, no imposed lookahead, and few abstractions. It is not difficult to change that profile. The literature contains many studies of the impact of hypertext on reading and writing (reviewed by Charney, 1994), but the contribution of 'structure-management' has not been separated out – an oversight that may well vitiate many of the conclusions so far drawn in comparisons between different writing environments.

D. Studying a Fresh Domain

The framework needs to be tested in a domain which is unfamiliar and where a variety of different notations and environments are available. Moreover, we wish to distinguish between routine design (creating a variant of a familiar pattern) and creative design. According to the underlying theory of the framework, these two cases will have different profiles of cognitive dimensions (lookahead acceptable in the former, absolutely barred in the latter, for instance, if existing research on design in familiar and unfamiliar contexts is correct). A domain will be chosen where systems for both types of design have been successfully produced, and the systems will be compared to discover whether they differ in the predicted ways. Preliminary discussions have taken place with the Martin Centre of the Cambridge University Dept. of Architecture, which pursues research into CAD systems for creative architectural design.

E. Dissemination

In the practical realm, the overall target of the approach is a body of knowledge on how to design artificial languages in the light of cognitive psychological principles, presented in a form usable by practitioners. Green will be giving tutorials at workshops and conferences and writing monographs and articles in practitioners' journals.

It is not easy to explain the different dimensions in the abstract, less still their trade-offs. Green therefore intends to build small demonstration devices, exemplifying various possibilities (e.g. two versions of a bibliographic system, one with high viscosity and low abstractions, one the opposite). Preliminary versions have already been built for some examples, using very basic tools, but more sophisticated software building kits are now available.

TECHNOLOGY-MEDIATED COMMUNICATION *(Sellen)*

Introduction

Recent technological advancements have resulted in vast improvements, both technically and financially, for the development of videoconferencing systems. Along with these advancements comes a renewed interest in such technology as a way of enabling people to meet from remote locations. This technology could have a profound impact on the way we work and socialize, and has been suggested for a range of different purposes, from support for working at home, to making medical expertise available to remote geographical areas. The renewed interest in video for communication is reflected by the growing number of experimental video systems or "media spaces" that exist in research laboratories around the world. Sellen was involved in the design of one such media space at the University of Toronto (Mantei et al., 1991). Since arriving in Cambridge, she has been working in collaboration with Rank Xerox EuroPARC which also has its own media space (4.72).

Sellen's research has explored the ways in which communicative behaviour might be altered when mediated by such technology, usually by comparing it to behaviour in a face-to-face situation. This work has focussed on two aspects of communication: the effects of mediation on conversational processes (turn-taking, for example), and the ways in which people alter their behaviour when working together through video-link technology. These theoretical findings have practical implications for the design of technology, but they also shed light on the kinds of cues that are used in communication, and the cognitive processes that underlie collaborative work.

A. Speech Patterns and Conversational Process

Part of the promise of video technology is the possibility of being able to simulate, for remote participants, some of what people share when they meet in the same physical space. What we have yet to understand is the extent to which the visual channel can provide these benefits. Conversely, we have yet to appreciate how video-mediated interaction may differ fundamentally from sharing the same physical space, including the possibility that it may significantly alter conversational behaviour. Two experiments were carried out (4.71, 4.73) to compare face-to-face and audio-only conversations to those held over three kinds of videoconferencing systems. One videoconferencing system was specifically developed to support selective gaze in a multi-party conversation (Sellen, Buxton & Arnott, 1992). Particular attention was paid to effects of the medium on the surface structure of conversation, measured by automatically tracking the on-off patterns of speech by the participants (i.e., turn-taking and the like).

In terms of the speech measures, only the face-to-face condition showed any significant differences from any other condition, giving rise to more interruptions and fewer formal handovers of the floor than the technology-mediated conditions. The results suggest that mediated conversations are more formal and less interactive than face-to-face conversations because participants feel more disengaged from the situation. In this respect, the audio-only and video systems examined in these studies were equivalent. However, additional analyses revealed that visual access in mediated conversations, and the particular design of the different videoconferencing systems, had important effects on subjects' behaviour and opinions. For example, while the system that supported selective gaze showed no benefits in terms of turn-taking behaviour, it did afford conversational acts such as asides and parallel conversations, which the other videoconferencing systems did not.

B. Collaborative Work in a Media Space

A second phase of the research benefitted from collaboration with ethnomethodologists Christian Heath and Paul Luff at EuroPARC. This marked a shift in emphasis from systems which support face-to-face conversation to systems which support collaborative work. Heath and Luff have emphasized the limitations of designing media spaces around face-to-face conversation, pointing out that much of collaborative work is done by people jointly focussing on physical artifacts and shared workspaces, by monitoring one's co-workers in relation to their activity, and by monitoring one's co-workers in the periphery of the field of vision. This led us to suggest ways in which we might reconfigure media spaces to support these aspects of collaboration (4.154). Heath and Luff have also demonstrated that this ability to monitor activity in the periphery, and to achieve the normal performative impact of gesture and gaze, is undermined when mediated by video technology.

Taken together, these findings motivated us to try various ways of expanding access to the remote space by building some experimental systems and observing their benefits and drawbacks in collaborative tasks (4.72). In the first study, we built an experimental system in which four switchable cameras were deployed in each of two remote offices, and observed participants using the system to collaborate on two tasks. The new views allowed increased access to task-related artifacts; indeed, users preferred these views to more typical "face-to-face" ones. However, problems of establishing a joint frame of reference were exacerbated by the additional complexity of multiple cameras, and the disparate views they offered. In the second study, we provided multiple monitors to coincide with the multiple cameras offering co-workers continuous, multiple views of each other. This improved the transition from one view to another, and resulted in more frequent glances at the face-to-face view during conversation; but establishing a joint frame of reference was still a major difficulty. One practical result of these studies is the identification of important features which must be embodied in the technology. From a theoretical perspective, the studies emphasize the importance of a shared physical environment in establishing shared understanding. This "common ground" is necessary for smooth and efficient communication.

FUTURE PROPOSALS

Although work with experimental video systems over the last five years has led to a number of implications for design of this kind of technology, all of the studies thus far have taken place within the confines of the laboratory. The research has now reached the point where findings from the laboratory must be tested in field settings. Currently, with funding from Xerox, Sellen and colleagues at EuroPARC are negotiating the installation of a remote video link between designers of photocopiers at Rank Xerox's site in Welwyn Garden City, U.K., and the manufacturers of these machines in Venray, Holland. The installation of this link will offer a chance to: (1) observe and collect data on behavioural interaction over this link, and (2) implement a range of design ideas. For example, one plan is to provide multiple views (such as a document camera, a face-to-face camera, and a wide angle camera) and allow users at both sites to switch their view on the remote site. This will provide important data about which views are used and when they are used. In addition, blanket videotape recordings of interaction will provide data on conversational interaction over extended periods of time, making it possible to see whether people adapt their behaviour to the technology in the long term. These kinds of observation are obviously difficult to carry out in the laboratory, and will speak to the generalizability of such studies.

PUBLICATIONS (Excluding work done prior to arrival at APU)

Edited Books

4.1. Hoc, J-M., GREEN, T.R.G., Samurçay, R. & Gilmore, D.J. (Eds.). (1990). The Psychology of Programming. London: Academic Press.

Refereed Articles

4.2. Beardsworth, E. & BISHOP, D.V.M. (1994). Assessment of long-term verbal memory in children. Memory, 2, 129-148.

4.3. BELLAMY, R.K.E. (1990). A psychology of programming for design. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 1005-1006). Amsterdam: Elsevier Science Publishers, B.V.

4.4. BELLAMY, R.K.E. & Carroll, J.M. (1992). Re-structuring the programmer's task. International Journal of Man-Machine Studies, 37, 503-527.

4.5. Bird, J. & BISHOP, D.V.M. (1992). Perception and awareness of phonemes in phonologically impaired children. European Journal of Disorders of Communication, 27, 289-311.

4.6. BISHOP, D.V.M. (1993). Annotation: Autism, executive functions and theory of mind: A neuropsychological perspective. Journal of Child Psychology and Psychiatry, 34, 279-293.

4.7. BISHOP, D.V.M. (in press). Grammatical errors in specific language impairment: Competence or performance limitations? Applied Psycholinguistics.

4.8. BISHOP, D.V.M. (in press). Is specific language impairment a valid diagnostic category? Genetic and psycholinguistic evidence. Philosophical Transactions of the Royal Society B.
4.9. BISHOP, D.V.M., Hartley, J. & Weir, F. (1994). Why and when do some language-impaired children seem talkative? A study of initiation in conversations of children with semantic-pragmatic disorder. Journal of Autism and Developmental Disorders, 24, 177-197.
4.10. BISHOP, D.V.M., North, T. & Donlan, C. (in press). Genetic basis of specific language impairment: Evidence from a twin study. Developmental Medicine and Child Neurology.
4.11. Black, A., WRIGHT, P., Black, D. & Norman, K. (1992). Using dictionary information: Some factors influencing whether readers will check the meanings of unknown words in a text. Hypermedia, 4, 145-169.
4.12. Coltheart, V., PATTERSON, K. & Leahy, J. (in press). When a ROWS is a ROSE: Phonological effects in written word comprehension. Quarterly Journal of Experimental Psychology.
4.13. CUTLER, A. (1993). Phonological cues to open- and closed-class words in the processing of spoken sentences. Journal of Psycholinguistic Research, 22, 109-131.
4.14. CUTLER, A. (in press). Segmentation problems, rhythmic solutions. Lingua.
4.15. CUTLER, A. (in press). The perception of rhythm in language. Cognition.
4.16. CUTLER, A. & BUTTERFIELD, S. (1990). Durational cues to word boundaries in clear speech. Speech Communication, 9, 485-495.
4.17. CUTLER, A. & BUTTERFIELD, S. (1991). Word boundary cues in clear speech: A supplementary report. Speech Communication, 10, 335-353.
4.18. CUTLER, A. & BUTTERFIELD, S. (1992). Rhythmic cues to speech segmentation: Evidence from juncture misperception. Journal of Memory and Language, 31, 218-236.
4.19. CUTLER, A., KEARNS, R., NORRIS, D. & Scott, D.R. (1993). Problems with click detection: Insights from cross-linguistic comparisons. Speech Communication, 13, 401-410.
4.20. CUTLER, A., MCQUEEN, J., & ROBINSON, K. (1990). Elizabeth and John: Sound patterns of men's and women's names. Journal of Linguistics, 26, 471-482.
4.21. CUTLER, A. & Mehler, J. (1993). The periodicity bias. Journal of Phonetics, 21, 103-108.
4.22. CUTLER, A., Mehler, J., NORRIS, D. & Segui, J. (1992). The monolingual nature of speech segmentation by bilinguals. Cognitive Psychology, 24, 381-410.
4.23. CUTLER, A. & Otake, T. (in press). Mora or phoneme? Further evidence for language specific listening. Journal of Memory and Language.
4.24. CUTLER, A. & Scott, D.R. (1990). Speaker sex and perceived apportionment of talk. Applied Psycholinguistics, 11, 253-272.
4.25. Davies, S.P., Gilmore, D.J. & GREEN, T.R.G. (in press). Are objects that important? The effects of expertise and familiarity on the classification of object-oriented code. Human-Computer Interaction.
4.26. Franklin, S., Howard, D. & PATTERSON, K. (1994). Abstract word meaning deafness. Cognitive Neuropsychology, 11, 1-34.
4.27. Franklin, S., Howard, D. & PATTERSON, K. (in press). Abstract word anomia. Cognitive Neuropsychology.
4.28. GRAHAM, K.S., Hodges, J.R. & PATTERSON, K. (1994). The relationship between comprehension and oral

reading in progressive fluent aphasia. Neuropsychologia, 32, 299-316.
4.29. GREEN, T.R.G. (1990). The cognitive dimension of viscosity: A sticky problem for HCI. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 79-86). Amsterdam: Elsevier Science Publishers, B.V.
4.30. GREEN, T.R.G. (1991). Describing information artifacts with cognitive dimensions and structure maps. In D. Diaper & N. Hammond (Eds.), People and Computers VI: Proceedings of the HCI '91 Conference (pp. 297-315). Cambridge: Cambridge University Press.
4.31. GREEN, T.R.G. (in press). The cognitive dimensions of information structures. Technical Communication.
4.32. GREEN. T.R.G. & Hoc, J-M. (1991). What is cognitive ergonomics? Le Travail Humain, 54, 291-304.
4.33. GREEN, T.R.G. & Borning, A. (1990). The generalized unification parser: Modelling the parsing of notations. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 951-957). Amsterdam: Elsevier Science Publishers, B.V.
4.34. GREEN, T.R.G. & Doubleday, A. (in press). Linguistic regularity effects and cognitive processes. In Proc. 7th European Conf. on Cognitive Ergonomics.
4.35. GREEN, T.R.G., Gilmore, D.J., BLUMENTHAL, B.B., Davies, S. & Winder, R. (1992). Towards a cognitive browser for OOPS. International Journal of Human-Computer Interaction, 4, 1-34.
4.36. GREEN. T.R.G., Petre, M. & BELLAMY, R.K. (1991). Comprehensibility of visual and textual programs: A test of Superlativism against the 'match-mismatch' conjecture. In J. Koenemann-Belliveau, T.G. Moher & S.P. Robertson (Eds.), Empirical Studies of Programmers - 4th Workshop (pp. 121-146). Norwood, New Jersey: Ablex Publishing Company.
4.37. GREEN, T.R.G. & Petre, M. (in press). When visual programs are harder to read than textual programs. In G.C. van der Veer, M.J. Tauber, S. Bagnarola & M. Antalovits (Eds.), ECCE-6: Proceedings of the 6th European Conference on Cognitive Ergonomics (Lake Balaton, Hungary, 1992).
4.38. HENDRY, D.G. & GREEN, T.R.G. (1993). CogMap: A visual description language for spreadsheets. Journal of Visual Languages and Computing, 4, 35-54.
4.39. HENDRY, D.G. & GREEN, T.R.G. (1993). Spelling mistakes: How well do correctors perform? In S. Ashlund, K. Mullet, A. Henderson, E. Hollnagel & T. White (Eds.), INTERCHI 93 Adjunct Proceedings (Conference on Human Factors in Computing Systems) (pp. 83-84). ACM/IFIP.
4.40. HENDRY, D.G. & GREEN, T.R.G. (in press). Creating, comprehending, and explaining spreadsheets: A cognitive interpretation of what discretionary users think of the spreadsheet model. Int. J. Human-Computer Studies.
4.41. Hodges, J.R., PATTERSON, K., Oxbury, S. & Funnell, E. (1992). Semantic dementia: Progressive fluent aphasia with temporal lobe atrophy. Brain, 115, 1783-1806.
4.42. Hodges, J., PATTERSON, K. & Tyler, L. (in press). Loss of semantic memory: Implications for the modularity of mind. Cognitive Neuropsychology.
4.43. Howard, D., PATTERSON, K., Wise, R., Brown, W.D., Friston, K., Weiller, C. & Frackowiak, R. (1992). The cortical localization of the lexicons: Positron Emission Tomography evidence. Brain, 115, 1769-1782.
4.44. Jusczyk, P.W., CUTLER, A. & Redanz, N.J. (1993). Infants' preference for the predominant stress patterns

of English words. Child Development, 64, 675-687.
4.45. MCQUEEN, J.M. (1991). The influence of the lexicon on phonetic categorisation: Stimulus quality in word-final ambiguity. Journal of Experimental Psychology: Human Perception and Performance, 17, 433-443.
4.46. MCQUEEN, J.M. (1993). Rhyme decisions to spoken words and nonwords. Memory and Cognition, 21, 210-222.
4.47. MCQUEEN, J.M., NORRIS, D. & CUTLER, A. (1994). Competition in spoken word recognition: Spotting words in other words. Journal of Experimental Psychology: Learning, Memory, and Cognition, 20, 621-638.
4.48. Modugno, F.M., GREEN, T.R.G. & Myers, B. (in press). Visual programming in a visual domain: a case study of cognitive dimensions. In People and Computers IX: Proc. BCS HCI Conference.
4.49. Monsell, S., PATTERSON, K., Graham, A., Hughes, C. & MILROY, R. (1992). Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status. Journal of Experimental Psychology: Learning, Memory, and Cognition, 18, 452-467.
4.50. Morton, J., Sasanuma, S., PATTERSON, K. & Sakuma, N. (1992). The organization of the lexicon in Japanese: Single and compound kanji. British Journal of Psychology, 83, 517-531.
4.51. Nix, A.J., Mehta, G., Dye, J. & CUTLER, A. (1993). Phoneme detection as a tool for comparing perception of natural and synthetic speech. Computer Speech and Language, 7, 211-228.
4.52. NORRIS, D. (in press). A quantitative multiple-levels model of reading aloud. Journal of Experimental Psychology: Human Perception and Performance.
4.53. NORRIS, D.G. (1990). How to build a connectionist idiot (savant). Cognition, 35, 277-291.
4.54. NORRIS, D. (in press). Shortlist: A connectionist model of continuous speech recognition. Cognition.
4.55. NORRIS, D. (in press). Signal detection theory and modularity: On being sensitive to the power of bias models of semantic priming. Journal of Experimental Psychology: Human Perception and Performance.
4.56. Otake, T., Hatano, G., CUTLER, A. & Mehler, J. (1993). Mora or syllable? Speech segmentation in Japanese. Journal of Memory and Language, 32, 258-278.
4.57. VAN OOYEN, B., CUTLER, A. & NORRIS, D.G. (1992). Detection of vowels and consonants with minimal acoustic variation. Speech Communication, 11, 101-108.
4.58. PATTERSON, K.E. (1990). Alexia and neural nets. Japanese Journal of Neuropsychology, 6, 90-99.
4.59. PATTERSON, K.E. (1990). Basic processes of reading - Do they differ in Japanese and English? Japanese Journal of Neuropsychology, 6, 4-14.
4.60. PATTERSON, K., GRAHAM, N. & Hodges, J. (1994). Reading in Alzheimer's type dementia: A preserved ability? Neuropsychology, 8, 395-407.
4.61. PATTERSON, K., GRAHAM, N. & Hodges, J.R. (1994). The impact of semantic memory loss on phonological representations. Journal of Cognitive Neuroscience, 6, 57-69.
4.62. PATTERSON, K. & Hodges, J.R. (1992). Deterioration of word meaning: Implications for reading. Neuropsychologia, 30, 1025-1040.
4.63. PATTERSON, K. & Vargha-Khadem, F. (1991). Neuropsychological observations on the affinity between reading and phonological abilities. Mind and Language, 6, 141-145.
4.64. PATTERSON, K. & WILSON, B. (1990). A ROSE is a ROSE or a NOSE: A deficit in initial letter

identification. Cognitive Neuropsychology, 7, (5/6), 447-477.
4.65. Petre, M. & GREEN, T.R.G. (1990). Where to draw the line with text: Some claims by logic designers about graphics in notation. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 463-468). Amsterdam: Elsevier Science Publishers, B.V.
4.66. Petre, M. & GREEN. T.R.G. (1992). Requirements of graphical notations for professional users: Electronic CAD systems as a case study. Le Travail Humain, 55, 47-70.
4.67. Petre, M. & GREEN, T.R.G. (1993). Learning to read graphics: Some evidence that 'seeing' an information is an acquired skill. Journal of Visual Languages and Computing, 4, 55-70.
4.68. Powell, R. & BISHOP, D.V.M. (1992). Clumsiness and perceptual problems in children with specific language impairment. Developmental Medicine and Child Neurology, 34, 755-765.
4.69. Price, C., Wise, R., Ramsay, S., Friston, K., Howard, D., PATTERSON, K. & Frackowiak, R. (1992). Regional response differences within the human auditory cortex when listening to words. Neuroscience Letters, 146, 179-182.
4.70. Price, C., Wise, R., Watson, J., PATTERSON, K., Howard, D. & Frackowiak, R. (in press). Brain activity during reading: The effects of exposure duration and task. Brain.
4.71. SELLEN, A.J. (in press). Remote conversations: The effects of mediating talk with technology. To appear in Human-Computer Interaction.
4.72. Gaver, W., SELLEN, A., Heath, C. & Luff, P. (1993). One is not enough: Multiple views in a media space. Proceedings of INTERCHI '93, Amsterdam, April 24-29.
4.73. SELLEN, A.J. (1992). Speech patterns in video-mediated conversations. Proceedings of SIGCHI '92, Monterey, CA, May, 1992.
4.74. STARK, H.A. (1990). Pop-up windows and memory for text. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction - INTERACT '90 (pp. 67-72). Amsterdam: Elsevier Science Publishers, B.V.
4.75. STARK, H.A. (1990). What do readers do to pop-ups, and pop-ups do to readers? In R. McAleese & C. Green (Eds.), Hypertext: State of the Art (pp. 2-9). Oxford: Intellect Ltd.
4.76. WILSON, B. & PATTERSON, K. (1990). Rehabilitation for cognitive impairment: Does cognitive psychology apply? Applied Cognitive Psychology, 4, 247-260.

4.77. WRIGHT, P. (1990). Homework: An international comparison of behavioural researchers' use of computers for work at home. In M. Feeney & K. Merry (Eds.), Information Technology and the Research Process (pp.130-145). London: Bowker-Saur.
4.78. WRIGHT, P. (1991). Information design: An informal review of the past decade. Information Design Journal, 6/3.
4.79. WRIGHT, P., Holborn, D. & Stokes, B. (1993). A British view of document design: A conversation with Patricia Wright. Issues in Writing, 5, 116-134.
4.80. WRIGHT, P. & Hull, A.J. (1990). How people give verbal instructions. Applied Cognitive Psychology, 4, 153-174.

4.81. WRIGHT, P., Hull, A.J. & Black, D. (1990). Integrating diagrams and text. The Technical Writing Teacher, Vol. XVII, 244-254.

4.82. WRIGHT, P., Hull, A.J. & LICKORISH, A. (1993). Navigating in a hospital outpatients' department: The merits of maps and wall signs. Journal of Architectural Planning and Research, 10, 76-89.

4.83. WRIGHT, P. & Lawrence, G. (1994). Design of case report forms for clinical trials. In J. Lloyd & A. Raven (Eds.), ACRPI Handbook of Clinical Research (pp. 209-235). London: Churchill Medical Communications.

4.84. WRIGHT, P. & LICKORISH, A. (1990). An empirical comparison of two navigation systems for two hypertexts. In R. McAleese & C. Green (Eds.), Hypertext: State of the Art (pp.84-93). Oxford: Intellect Ltd.

4.85. WRIGHT, P. & LICKORISH, A. (in press). Menus and memory load: navigation strategies in interactive search tasks. International Journal of Human-Computer Studies.

4.86. WRIGHT, P., LICKORISH, A. & MILROY, R. (1994). Remembering while mousing: The cognitive costs of mouse clicks. SIGCHI Bulletin, 26, 41-45.

4.87. WRIGHT, P., LICKORISH, A., & Hull, A.J. (1990). The importance of iterative procedures in the design of location maps for the built environment. Information Design Journal, 6, 67-78.

4.88. WRIGHT, P., LICKORISH, A., Hull, A.J. & UMMELEN, N. (in press). Graphics in written directions: Appreciated by readers but not writers. Applied Cognitive Psychology.

4.89. Wydell, T.N., PATTERSON, K.E. & Humphreys, G.W. (1993). Phonologically mediated access to meaning for Kanji: Is a Rows still a Rose in Japanese KANJI? Journal of Experimental Psychology: Learning, Memory, and Cognition, 19, 491-514.

Submitted

4.90. GREEN, T.R.G. & HENDRY, D.G. Spelling correctors and spelling mistakes. (Manuscript submitted to Transactions of Office Information Systems).

4.91. GREEN, T.R.G., Davies, S.P. & Gilmore, D.J. Contributions of cognitive psychology to HCI. (Manuscript submitted to Zeitschrift fur Psychologie).

4.92. GREEN, T.R.G. & Petre, M. (a) Cognitive dimensions as discussion tools for programming language design. (Manuscript submitted to Human Computer Interaction).

4.93. GREEN, T.R.G. & Petre, M. (b) Cognitive dimensions of visual programming environments. (Manuscript submitted to IEEE Computer)

4.94. Hesketh, A. & BISHOP, D.V.M. (submitted). Agrammatism and adaptation theory. (Manuscript submitted to Aphasiology)

4.95. NORRIS, D., MCQUEEN, J.M. & CUTLER, A. Competition and segmentation in spoken word recognition. (Manuscript submitted to Journal of Experimental Psychology: Learning, Memory, and Cognition)

4.96. Petre, M. & GREEN, T.R.G. Using graphical representations requires skill, and graphical readership is an 'acquired' skill. (Manuscript submitted to Journal of AI in Education).

4.97. STRAIN, E., PATTERSON, K. & Seidenberg, M.S. (1994). Semantic effects in single-word naming. (Manuscript submitted to Journal of Experimental Psychology: Learning, Memory and Cognition)

4.98. Wydell, T.N., Butterworth, B. & PATTERSON, K. (1994). The inconsistency of consistency effects in reading: The case of Japanese Kanji. (Manuscript submitted to Journal of Experimental Psychology: Learning,

Memory and Cognition)

Invited Chapters and Commentaries

4.99. BELLAMY, R.K.E. & Gilmore, D.J. (1990). Programming plans: Internal or external structures. In K.J. Gilhooly, M.T.G. Keane, R.H. Logie & G. Erdos (Eds.), Lines of Thinking: Reflections on the Psychology of Thought, Vol. 2 (pp.59-71). Chichester: John Wiley & Sons Limited.

4.100. BISHOP, D.V.M. (1992). The biological basis of specific language impairment. In P. Fletcher & D. Hall (Eds.), Specific Speech and Language Disorders in Children: Correlates and Outcomes (pp. 2-17). London: Whurr Publications.

4.101. BISHOP, D.V.M. (1994). Developmental disorders of speech and language. In M. Rutter, L. Hersov & E. Taylor (Eds.), Child and Adolescent Psychiatry, 3rd edition (pp. 546-568). Oxford: Blackwell Scientific Publications.

4.102. Botelho da Silva, T. & CUTLER, A. (1993). Ill-formedness and transformability in Portuguese idioms. In C. Cacciari & P. Tabossi (Eds.), Idioms: Processing, Structure, and Interpretation (pp. 129-143). Hillsdale, N.J.: Erlbaum.

4.103. CUTLER, A. (1990). Exploiting prosodic probabilities in speech segmentation. In G.T.M. Altmann (Ed.), Cognitive Models of Speech Processing: Psycholinguistic and Computational Perspectives (pp.105-121). Cambridge, MA: MIT Press.

4.104. CUTLER, A. (1990). From performance to phonology: Comments on Beckman and Edwards's paper. In J. Kindston & M. Beckman (Eds.), Between the Grammar and Physics of Speech (pp.208-214). Cambridge: Cambridge University Press.

4.105. CUTLER, A. (1991). Linguistic rhythm and speech segmentation. In J. Sundberg, L. Nord & R. Carlson (Eds.), Music, Language, Speech and Brain (pp. 157-166). Houndsmill, Basinstoke: Macmillan Press.

4.106. CUTLER, A. (1991). Processing constraints of the native phonological repertoire on the native language. In Y. Tohkura, E. Vatikiotis-Bateson & Y. Sagisaka (Eds.), Speech Perception, Production and Linguistic Structure (pp. 275-278). Tokyo: IOS Press.

4.107. CUTLER, A. (1991). The production and perception of word boundaries. In Y. Tohkura, E. Vatikiotis-Bateson & Y. Sagisaka (Eds.), Speech Perception, Production and Linguistic Structure (pp. 419-425). Tokyo: IOS Press.

4.108. CUTLER, A. (1992). Psychology and the segment. In G.J. Docherty & D.R. Ladd (Eds.), Papers in Laboratory Phonology II: Gesture, Segment, Prosody (pp. 290-295). Cambridge: Cambridge University Press.

4.109. CUTLER, A. (1992). Why not abolish psycholinguistics? In W.U. Dressler, H.C. Luschützky & O.E. Pfeiffer (Eds.), Phonologica 1988 (pp. 77-87). Cambridge: Cambridge University Press.

4.110. CUTLER, A. (in press). Marked and unmarked segmentation strategies? In H.C. Nusbaum & J.G. Goodman (Eds.), The Transition from Recognizing Speech Sounds to Recognizing Spoken Words. Cambridge, MA: MIT Press.

4.111. CUTLER, A. (in press). Prosody and the word boundary problem. In J. Morgan & K. Demuth (Eds.), Signal to Syntax. Hillsdale, N.J.: Lawrence Erlbaum Associates.

4.112. CUTLER, A. (in press). Spoken word recognition and production. In J.L. Miller & P.D. Eimas (Eds.),

Speech, Language and Communication. Volume 11 of E.C. Carterette & M.P. Friedman (Eds.), Handbook of Perception and Cognition. New York: Academic Press.
4.113. CUTLER, A.& MCQUEEN, J.M. (in press). The recognition of lexical units in speech. In B. de Gelder & J. Morais (Eds.), From Spoken to Written Language. Cambridge, MA: The MIT Press.
4.114. GREEN, T.R.G. (1990). Limited theories as a framework for human-computer interaction. In D. Ackermann & M.J. Tauber (Eds.), Mental Models and Human-Computer Interaction 1 (pp. 3-39). Elsevier Science Publishers B.V. North-Holland.
4.115. GREEN, T.R.G. (1990). Programming languages as information structures. In J-M. Hoc, T.R.G. Green, R. Samurcay & D.J. Gilmore (Eds.), The Psychology of Programming (pp. 117-137). London: Academic Press.
4.116. GREEN, T.R.G. (1990). The nature of programming. In J-M Hoc, T.R.G. Green, R. Samurcay & D.J. Gilmore (Eds.), The Psychology of Programming (pp. 21-44). London: Academic Press.
4.117. GREEN, T.R.G. (1991). User modelling: the information-processing perspective. In J. Rasmussen, H.B. Andersen & N.O. Bernsen (Eds.), Research Directions in Cognitive Science: A European Perspective, Vol. 3: Human Computer Interaction (pp. 27-57). London: Lawrence Erlbaum Associates.
4.118. GREEN, T.R.G. (in press). Why software engineers don't listen to what psychologists don't tell them anyway. In D. Gilmore & R. Winder (Eds.), User-Centred Requirements for Software Engineering Environments. North-Holland: Elsevier.
4.119. MCQUEEN, J.M. (in press). Processing versus representation: A reply to Ohala and Ohala. In B. Connell, A. Arvaniti & I. Watson (Eds.), Papers in Laboratory Phonology IV. Cambridge: Cambridge University Press.
4.120. MCQUEEN, J.M. & CUTLER, A. (in press). Morphology in word recognition. In A.M. Zwicky & A. Spencer (Eds.), A Handbook of Morphology. Oxford: Blackwell.
4.121. Mehler, J. & CUTLER, A. (1990). Psycholinguistic implications of phonological diversity among languages. In Massimo Piattelli Palmarini (Ed.), Cognitive Science in Europe (pp. 119-134). GOLEM Monograph No. 1.
4.122. Mendelsohn, P., GREEN, T.R.G. & Brna, P. (1990). Programming languages in education: The search for an easy start. In J-M. Hoc, T.R.G. Green, R. Samurcay & D.J. Gilmore (Eds.), The Psychology of Programming (pp. 175-200). London: Academic Press.
4.123. NORRIS, D.G. (1990). A dynamic-net model of human speech recognition. In G.T.M. Altmann (Ed.), Cognitive Models of Speech Processing: Psycholinguistic and Computational Perspectives (pp.87-105). Cambridge, MA: MIT Press.
4.124. NORRIS, D. (1991). Connectionism: A case for modularity. In D.A. Balota, G.B. Flores d'Arcais & K. Rayner (Eds.), Comprehension Processes in Reading (pp.331-343). Hillsdale, N.J.: Lawrence Erlbaum Associates.
4.125. NORRIS, D.G. (1992). Connectionism: A new class of bottom up model. In R.G. Reilly & N.E. Sharkey (Eds.), Connectionist Approaches to Language Processing (pp. 351-371). Hove, Sussex: Lawrence Erlbaum Associates.
4.126. PATTERSON, K. (1992). Phonology in reading. The Psychologist, 5, p. 314.
4.127. PATTERSON, K. (1994). Reading, writing and rehabilitation: A reckoning. In M.J. Riddoch & G.W.

Humphreys (Eds.), Cognitive Neuropsychology and Cognitive Rehabilitation (pp. 425-447). Hove: Lawrence Erlbaum Associates.
4.128. PATTERSON, K. & MARCEL, A.J. (1992). Phonological ALEXIA or PHONOLOGICAL Alexia? In J. Alegria, D. Holender, J. Junça de Morais & M. Radeau (Eds.), Analytic Approaches to Human Cognition (pp. 259-274). Amsterdam: Elsevier Science Publishers B.V.
4.129. Penz, F., Bourne, M. & WRIGHT, P. (1992). Tools for design: A controlled experiment comparing computer work with traditional hand drawings. In F. Penz (Ed.), Tools for Design (pp. 3-14). Longmans.
4.130. Sasanuma, S. & PATTERSON, K. (in press). The consequences of impaired comprehension for word reading in Japanese and English. In B. de Gelder & J. Morais (Eds.), From Spoken to Written Language. Cambridge, MA: MIT Press.
4.131. Schiele, F. & GREEN, T.R.G. (1990). HCI formalisms and cognitive psychology: The case of task-action grammar. In M. Harrison & H. Thimbleby (Eds.), Formal Methods in Human-Computer Interaction (pp. 9-62). Cambridge: Cambridge University Press.
4.132. STARK, H.A. (1991). Support for multi-attribute choice in OIS: From decision rules to decision tools, and back again. In A.A. Verrijn-Stuart, H.G. Sol & P. Hammersley (Eds.), Support Functionality in the Office Environment (pp. 159-179). Elsevier Science Publishers B.V. (North-Holland).
4.133. WRIGHT, P. (1990). Hypertexts as an interface for learners: Some human factors issues. In D. Jonassen & H. Mandl (Eds.), Designing Hypermedia for Learning (pp. 169-184). Berlin: Heidelberg: Springer-Verlag.
4.134. WRIGHT, P. (1991). Designing and evaluating documentation for IT users. In B. Shackel & S. Richardson (Eds.), Human Factors for Informatics Usability (pp.343-358). Cambridge: Cambridge University Press.
4.135. WRIGHT, P. (1991). Quality: An excellent idea? In Proceedings of the First Conference on Quality in Documentation (pp. 9-24) (Waterloo, Canada, October 1991). University of Waterloo: The Centre for Professional Writing.
4.136. WRIGHT, P. (1991). Review of The Society of Text: Hypertext, hypermedia, and the social construction of information, by E. Barrett (Ed.), MIT Press, 1989. BCS HCI Newsletter, No.16 (April), 17-19.
4.137. WRIGHT, P. (1992). Cognitive overheads and prostheses: Some issues in evaluating hypertexts. In Hypertext '91. Proceedings of Third ACM Conference on Hypertext (pp. 1-12). (San Antonio, Texas, Dec. 15-18 1991), ACM.
4.138. WRIGHT, P. (1993). To jump or not to jump: Strategy selection while reading electronic texts. In C. McKnight, A. Dillon & J. Richardson (Eds.), Hypertext: A Psychological Perspective (pp. 137-152). Chichester: Ellis Horwood.
4.139. WRIGHT, P. (1994). Enhancing the usability of written instructions. In H. Zwaga & T. Boersema (Eds.), Public Graphics: Visual Information for Everyday Use. Utrech.
4.140. WRIGHT, P. (in press). Quality or usability? Quality writing provokes quality reading. In M. Steehouder, C. Jansen & R. Verheijen (Eds.), Quality in Documentation. Amsterdam: Editions Rodopi.
Conference Proceedings
4.141. ALLERHAND, M., BUTTERFIELD, S., CUTLER, A. & Patterson, R. (1992). Assessing syllable strength via

an auditory model. In Proceedings of the Institute of Acoustics, Vol. 14, part 6 (pp. 297-304).
4.142. Baurén, M., GREEN, T.R.G. & Petre, M. (1992). From PLOP to PLITH: A cognitive model of programming pointer problems. Psychology of Programming Interest Group Annual Workshop, Paris, 1992.
4.143. BELLAMY, R.K.E. & Carroll, J.M. (1990). Case-based reuse. In Proceedings of the ACM SIGPLAN Symposium on Object-Oriented Programming Emphasizing Practical Applications. New York.
4.144. BLUMENTHAL, B. (1993). Expert programmers' assessments of robustness, stability, and sources of expertise in the programming process. Proc. East-West Int. Conf. on Human-Computer Interaction. Moscow.
4.145. BUTTERFIELD, S. & CUTLER, A. (1990). Intonational cues to word boundaries in clear speech? In Proceedings of the Institute of Acoustics, (November 1990), 12, (pp. 87-94).
4.146. CUTLER, A. (1991). Prosody in situations of communication: Salience and segmentation. In Proceedings of the XIIth International Congress of Phonetic Sciences, Vol. 1 (pp. 264-270), (Aix-en-Provence, France, Aug 19-24, 1991).
4.147. CUTLER, A. (1993). Language-specific processing: Does the evidence converge? In G. Altmann and R. Shillcock (Eds.), Cognitive Models of Speech Processing: The Sperlonga Meeting II (pp. 115-123). Hillsdale, N.J.: Lawrence Erlbaum Associates.
4.148. CUTLER, A. (1993). Segmenting speech in different languages. The Psychologist, 6, 453-455.
4.149. CUTLER, A. & BUTTERFIELD, S. (1990). Syllabic lengthening as a word boundary cue. In R. Seidl (Ed.), Proceedings of the 3rd Australian International Conference on Speech Science and Technology (pp. 324-328), (Melbourne, November 1990). Canberra: Australian Speech Science and Technology Association.
4.150. CUTLER, A. & Fear, B. (1991). Categoricality in acceptability judgments for strong versus weak vowels. In Proceedings of the ESCA Workshop on Phonetics and Phonology of Speaking Styles: Reduction and Elaboration in Speech Communication (pp. 18-1 - 18-5), (Barcelona, Catalonia, Spain 30 Sept-2 Oct, 1991).
4.151. CUTLER, A., KEARNS, R., NORRIS, D. & Scott, D.R. (1992). Listeners' responses to extraneous signals coincident with English and French speech. In Proceedings of the 4th Australian International Conference on Speech Science and Technology (pp. 666-671). Canberra: Australian Speech Science and Technology Association.
4.152. CUTLER, A., NORRIS, D. & VAN OOYEN, B. (1990). Vowels as phoneme detection targets. In Proceedings of the International Conference on Spoken Language Processing, Vol. 1 (pp. 581-584), Kobe, Japan.
4.153. CUTLER, A. & Robinson, T. (1992). Response time as a metric for comparison of speech recognition by humans and machines. In Proceedings ICSLP 92 - International Conference on Spoken Language Processing, Volume 1 (pp. 189-192). Edmonton: University of Alberta.
4.154. Heath, C., Luff, P., & SELLEN, A.J. (In press). Reconfiguring media space. Proceedings of the British Telecom POTS to PANS Symposium, March, 1994.
4.155. HENDRY, D., GREEN, T.R.G., Gilmore, D. & Davies, S. (1992). Improving the communicability of spreadsheet designs: annotating with descriptive tags. Psychology of Programming Interest Group Annual Workshop.
4.156. MCQUEEN, J.M. & Briscoe, E.J. (1991). A computational tool for examining lexical segmentation in

continuous speech. In Eurospeech 91: Proceedings of the 2nd European Conference on Speech Communication and Technology, Vol. 2 (pp. 697-700). Genova, Italy, 24-26 September.
4.157. MCQUEEN, J.M. & CUTLER, A. (1992). Words within words: Lexical statistics and lexical access. In Proceedings ICSLP 92 - International Conference on Spoken Language Processing, Volume 1 (pp. 221-224). Edmonton: University of Alberta.
4.158. NORRIS, D. (1991). Rewiring lexical networks on the fly. In Eurospeech 91: Proceedings of the 2nd European Conference on Speech Communication and Technology, Vol. 1 (pp. 117-120). Genova, Italy, 24-26 September.
4.159. NORRIS, D. (1991). The constraints on connectionism. The Psychologist: Bulletin of the British Psychological Society, 4, 293-296.
4.160. NORRIS, D. (1993). Bottom-up connectionist models of interaction. In G. Altmann and R. Shillcock (Eds.), Cognitive Models of Speech Processing: The Sperlonga Meeting II (pp. 211-234). Hillsdale, N.J.: Lawrence Erlbaum Associates.
4.161. NORRIS, D., MCQUEEN, J. & CUTLER, A. (in press). Competition and segmentation in spoken word recognition. In Proceedings of the 1994 International Conference on Computer Speech and Language Processing (Yokohama, Japan).
4.162. NORRIS, D., VAN OOYEN, B. & CUTLER, A. (1992). Speeded detection of vowels and steady-state consonants. In Proceedings ICSLP 92 - International Conference on Spoken Language Processing, Volume 2 (pp. 1055-1058). Edmonton: University of Alberta.
4.163. VAN OOYEN, B. (1993). Detection of vowels and consonants by human listeners: Effect of minimising auditory memory load. In Eurospeech '93: Proceedings of the 3rd European Conference on Speech Communication and Technology (pp. 1507-1510), (Berlin, September, 1993).
4.164. VAN OOYEN, B., CUTLER, A. & Bertinetto, P.M. (1993). Click detection in Italian and English. In Eurospeech '93: Proceedings of the 3rd European Conference on Speech Communication and Technology (pp. 681-684) (Berlin, September, 1993).
4.165. VAN OOYEN, B., CUTLER, A., & NORRIS, D. (1991). Detection times for vowels versus consonants. In Eurospeech 91: Proceedings of the 2nd European Conference on Speech Communication and Technology, Vol. 3 (pp. 1451-1454). Genova, Italy, 24-26 September.
4.166. PATTERSON, K., CROOT, K. & Hodges, J.R. (1994). Speech production: Insights from a study of progressive aphasia. In Proceedings of the 3rd International Conference on Spoken Language Processing (Yokohama, Japan).
4.167. Penz, F., Bourne, M. & WRIGHT, P. (1990). Tools for design: A controlled experiment comparing computer work with traditional hand drawings. In Proceedings of International Symposium on Computers in Architecture. Cambridge: Dept. of Architecture, University of Cambridge, p.1.
4.168. THURSTON, P. & NORRIS, D. (1991). A comparison of two compression functions used for noisy vowel detection with back-propagation networks. In Eurospeech 91: Proceedings of the 2nd European Conference on Speech Communication and Technology, Vol. 2 (pp. 995-998). Genova, Italy, 24-26 September.
4.169. WRIGHT, P. (1990). Technical reading and technical writing: Relevant research for technical authors. In

TecDOC '90 (pp. 1-5), (Proceedings of the 8th International Weekend Conference on Technical Communication and Documentation), London: Consert.
4.170. WRIGHT, P. (1990). What's specific about user interfaces of hypertext systems? It's what you can do, and the way you can do it. In A. Rizk, N. Streitz & J. Andre (Eds.), Hypertext: Concepts, Systems and Applications (pp. 358-359) (Proceedings of the European Conference on Hypertext, INRIA, France, November 1990). Cambridge: Cambridge University Press.
4.171. WRIGHT, P. (1991). Reading for use. The Psychologist, 4, p.74.
4.172. WRIGHT, P. (1991). What is Hypertext? Euro-Documentation, 1, 2-3.
4.173. WRIGHT, P. (1992). Information Design the linking agent. In Conference Proceedings of PIRA/RSA Design Festival, 2nd International Conference, 1-3 April, 1992. p1-11.
4.174. WRIGHT, P. & Hull, A. (1990). When do readers read pictures? In Preseedings - Forum 90 (pp. 115-119), Stockholm, Sweden.
4.175. WRIGHT, P. & UMMELEN, N. (1990). Given a diagram, when do readers read text? Postharvest - Forum 90, Box 38, S-124 21 Bandhagen, Sweden. p81.
4.176. Young, D., Altmann, G.T.M., CUTLER, A. & NORRIS, D. (1993). Metrical structure and the perception of time-compressed speech. In Eurospeech '93: Proceedings of the 3rd European Conference on Speech Communication and Technology (pp. 771-774), (Berlin, September, 1993).
Technical Reports and Theses
4.177. CUTLER, A. & BUTTERFIELD, S. (1991). Speech segmentation under difficult listening conditions. Project supported by IBM UK Scientific Centre, October 1988-January 1991. Final Report. Cambridge: Applied Psychology Unit, (pp.28), April.
4.178. CUTLER, A., NORRIS, D.G. & MCQUEEN, J.M. (in press). Modelling lexical access from continuous speech input. Annual Report, dokkyo International Center, Tokyo.

4.179. GREEN, T.R.G., Winder, R., Gilmore, D.J., Davies, S.P., HENDRY, D. & Joly, G. (1992). Designing a cognitive browser for object-oriented programming. AISB Quarterly, Newsletter of the Society for the Study of Artificial Intelligence and Simulation of Behaviour, Autumn, No. 81, 17-20.
4.180. MCQUEEN, J.M. (1991). Phonetic decisions and their relationship to the lexicon. Unpublished PhD Thesis, University of Cambridge.
4.181. PATTERSON, R., NORRIS, D., & CUTLER, A. (Eds.). (1990). Auditory/Connectionist Techniques for Speech (ACTS) Periodic Progress Report No. 1, and associated Annexe. CEC: Brussels, June 1990.
4.182. PATTERSON, R.D., NORRIS, D. & CUTLER, A. (Eds.). (1991). Auditory/Connectionist Techniques for Speech. (ACTS) Periodic Progress Report No. 2 and associated Annexes. Brussels: CEC.
4.183. PATTERSON, R.D., NORRIS, D. & CUTLER, A. (1992). Auditory/Connectionist Techniques for Speech. (ACTS) Periodic Progress Report No, 3. Brussels: CEC, July.
Dissemination
4.184. BISHOP, D.V.M. (1993). Cumulative Index to Journal of Child Psychology and Psychiatry 1960-92. Oxford: Pergamon Press.

4.185. CUTLER, A. (1992). Cross-linguistic differences in speech segmentation. MRC News, September, No. 56, 8-9.

4.186. CUTLER, A. (1992). Perception of speech: Psycholinguistic aspects. In W. Bright (Ed.), International Encyclopedia of Linguistics, Vol. II (pp. 181-183), Oxford: Oxford University Press.

4.187. WRIGHT, P. (1990). The uses of research on writing. The Manual, 3, pp. 5 and 15.

4.188. WRIGHT, P. (1991). What is Hypertext? The Manual, 4, p. 3.

4.189. WRIGHT, P. (1992). Information design: The linking agent. Desktop Publishing Commentary, 8, 6-11.

4.190. WRIGHT, P. (1992). Cognitive aspects of information handling. Subsumed into Task Force 2: The Technological Imperative. Original submissions available from British Library Document Supply Centre, Boston Spa, Yorkshire.

4.191. WRIGHT, P. (1992). Review of Hypertext in Context by C.McKnight, A. Dillon and S.Richardson. International Journal of Man-Machine Studies, 37, 389-391.

4.192. *WRIGHT, P. (1994). Presenting technical information: a review of research findings. In D. Oborne (Ed.), Ergonomics and Human Factors. Cheltenham, Glos: Edward Elgar. [Reprinted from 1977]

4.193. *WRIGHT, P. (1994). Phenomena, function and design: does information make a difference? In D. Oborne (Ed.), Ergonomics and Human Factors. Cheltenham, Glos: Edward Elgar. [Reprinted from 1986]

4.194. *WRIGHT, P. (1994). Communicating with the user. In D. Oborne (Ed.), Ergonomics and Human Factors. Cheltenham, Glos: Edward Elgar. [Reprinted from 1988]

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REFERENCES TO OTHER WORK

Anderson, J.R. (1993). Rules of the Mind. Erlbaum.

Bertin, J. (1981). Graphics and Graphic Information Processing. (Trans. W. J. Berg.) New York: de Gruyter.

BISHOP, D.V.M. (1987). The causes of specific developmental language disorder ("developmental dysphasia"). Journal of Child Psychology and Psychiatry, 28, 1-8.

BISHOP, D.V.M. (1989). Autism, Asperger's syndrome and semantic-pragmatic disorder: Where are the boundaries? British Journal of Disorders of Communication, 24, 107-121.

BISHOP, D.V.M. (1989). Test for the Reception of Grammar (2nd edition). Manchester: University of Manchester.

BISHOP, D.V.M. (1990). Handedness, clumsiness and developmental language disorders. Neuropsychologia, 28, 681-690.

BISHOP, D.V.M. (1992). The underlying nature of specific language impairment. Journal of Child Psychology & Psychiatry, 33, 1-64.

BISHOP, D.V.M. & Adams, C. (1989). Conversational characteristics of children with semantic-pragmatic disorder. II. What features lead to a judgement of inappropriacy? British Journal of Disorders of Communication, 24, 241-263.

BISHOP, D.V.M. & Adams, C. (1990). A prospective study of the relationship between specific language impairment, phonological disorders and reading retardation. Journal of Child Psychology and Psychiatry, 31, 1027-1050.

BISHOP, D.V.M. & Adams, C. (1991). What do referential communication tasks measure? A study of children with specific language impairment. Applied Psycholinguistics, 12, 199-215.

BISHOP, D.V.M. & Adams, C. (1992). Comprehension problems in children with specific language impairment: Literal and inferential meaning. Journal of Speech & Hearing Research, 35, 119-129.

BISHOP, D.V.M. & Rosenbloom, L. (1987). Classification of childhood language disorders. In W. Yule, M. Rutter (Eds.), Language Development and Disorders. Clinics in Developmental Medicine (double issue), nos. 101-2. (pp. 16-41) London: Mac Keith Press.

Caplan, R., Foy, J.G., Asarnow, R.F. & Sherman, T. (1990). Information processing deficits of schizophrenic children with formal thought disorder. Psychiatric Research, 31, 169-177.Coltheart, M., Curtis, B., Atkins, P. & Haller (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. Psychological Review, 100, 4, 589-608.

Card, S.K., Moran, T.P. & Newell, A. (1983). The Psychology of Human-Computer Interaction. Hillsdale, NJ: Lawrence Erlbaum Asociates Inc.

Charney, D. (1994). The impact of hypertext on processes of reading and writing. In S.J. Hilligoss & C.L. Selfe (Eds.), Literacy and Computers. New York: Modern Language Association.

CUTLER, A., Mehler, J., NORRIS, D. & Segui, J. (1983). A language specific comprehension strategy. Nature, 304, 5922, 159-160.

CUTLER, A., Mehler, J., NORRIS, D. & Segui, J. (1986). The syllable's differing role in the segmentation of French and English. Journal of Memory and Language, 25, 385-400.

CUTLER, A., Mehler, J., NORRIS, D. & Segui, J. (1987). Phoneme identification and the lexicon. Cognitive Psychology, 19, 141-177.

CUTLER, A. & NORRIS, D.G. (1988). The role of strong syllables in segmentation for lexical access. Journal of Experimental Psychology: Human Perception and Performance, 14, 113-121.

CUTLER, A. & NORRIS, D.(1979). Monitoring Sentence Comprehension. In W.E. Cooper and E.C.T. Walker (Eds.). Sentence Processing: Psycholinguistic Studies. Presented to Merrill Garrett, Erlbaum.

CUTLER, A. & NORRIS, D. (1988) The role of strong syllables in segmentation for lexical access. Journal of Experimental Psychology: Human Perception and Performance, 14, 113-121.

DeFries, J.C., Fulker, D.W. (1988). Multiple regression analysis of twin data: Aetiology of deviant scores versus individual differences. Acta Geneticae et Medicae Gemellologiae, 37, 205-216.

Elman, J. & McClelland, J. (1989). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. Journal of Memory and Language, 27, 143-165.

Farah, M. (1989). Semantic and perceptual priming: How similar are the underlying mechanisms? Journal of Experimental Psychology: Human Perception and Performance, 15, 188-194.

Gathercole, S.E. & Baddeley, A.D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. British Journal of Psychology, 81, 439-454.

Gaver, W., Moran, T., MacLean, A., Lövstrand, L., Dourish, P., Carter, K., and Buxton, W. (1992). Realizing a video environment: EuroPARC's RAVE system. Proceedings of CHI'92 (Monterey, California, 3 - 7 May). ACM,

New York, pp. 27 - 35.
Gopnik, M., & Crago, M. (1991). Familial aggregation of a developmental language disorder. Cognition, 39, 1-50.
Gray, W. & Anderson, J.R. (1987). Change-episodes in coding: When and how do programmers change their code? In G.M. Olson, S. Sheppard & E. Soloway (Eds.), Empirical Studies of Programmers: Second Workshop. Ablex.
Guthrie, J.T. (1988). Locating information in documents: An examination of a cognitive model. Reading Research Quarterly, 23, 178-199.
Humphreys, G.W., Riddoch, M.J. & Quinlan, P.T. (1988). Cascade processes in picture identification. Cognitive Neuropsychology, 5, 67-104.
LEE, W.O. (1993). Adapting to interface resources and circumventing interface problems: Knowledge development in a menu search task. In J.L. Alty, D. Diaper & S.P. Guest (Eds.), People and Computers VIII: Proceedings of the HCI '93 Conference (pp. 61-77). Cambridge: Cambridge University Press.
Leonard, L.B., Bortolini, U., Caselli, M.C., McGregor, K.K., & Sabbadini, L. (1992). Morphological deficits in children with specific language impairment: The status of features in the underlying grammar. Language Acquisition, 2, 151-179.
Mantei, M. M., Baecker, R. SELLEN, A. J., Wellman, B., and Buxton, W. (1991). Experiences in the use of a media space. Proceedings of SIGCHI '91, New Orleans, LA., pp. 203-208.
MARCEL, A.J. (1980). Surface dyslexia and beginning reading: A revised hypothesis of the pronunciation of print and its impairments. In M. Coltheart, K. Patterson and J.C. Marshall (Eds.)., Deep Dyslexia pp 227-258, London: Routeledge and Keegan Paul.
Marshall, J.C. & Newcombe, F. (1973). Patterns of paralexia: A psycholinguistic approach. Journal of Psycholinguistic Research, 2, 175-199.
MARSLEN-WILSON, W.D. & Welsh, A. (1978). Processing interactions and lexical access during word-recognition in continuous speech. Cognitive Psychology, 10, 29-63.
MAY, J., BARNARD, P.J. & BLANDFORD, A. (1993). Using structural descriptions of interfaces to automate the modelling of user cognition. User Modelling and User Adapted Interaction, 3, 27-64.
MAY, J., BARNARD, P.J., Boecker, M. & GREEN, A.J. (1990). Characterising structural and dynamic aspects of the interpretation of visual interface objects. In ESPRIT '90 Conference Proceedings (pp. 819-834), Brussels (November 1990), Dordrecht: Kluwer Academic Publishers.
MAY J., TWEEDIE, L. & BARNARD, P.J. (1993). Modelling user performance in visually based interactions. In J.L. Alty, D. Diaper & S.P. Guest (Eds.), People and Computers VIII: Proceedings of the HCI '93 Conference (pp. 95-110). Cambridge: Cambridge University Press.
McClelland, J. & Elman, J. (1986). The TRACE model of speech perception. Cognitive Psychology, 18, 1-86.
MCQUEEN, J.M. (1989). The use of lexical knowledge in phonetic categorisation. In J.P. Tubach & J.J. Mariani (Eds.)., Proceedings of Eurospeech '89, Vol. 2, 581-584. Edinburgh: CEP Consultants Ltd.
Mellish, C., Allport, D. et al. (1992). The TIC Message Analyser. University of Sussex Cognitive Science Research Paper 225.

NORRIS, D. (1986) Context effects without priming. Cognition, 22, 93-136.

O'Hara, K. & Payne, S.J. Cost of operations affects planfuless of problem-solving. (School of Psychology, University of Wales, Cardiff.) (Manuscript submitted for publication)

Plaut, D.C. & McClelland, J.L. (1993). Generalization with componential attractors: Word and nonword reading in an attractor network. In Proceedings of the 15th Annual Conference of the Cognitive Science Society. Hillsdale, NJ: Erlbaum.

Rapin, I. (1987). Developmental dysphasia and autism in pre-school children: characteristics and subtypes. In Proceedings of the First International Symposium on Specific Speech and Language Disorders in Children. (pp. 20-35). London: AFASIC.

Redlich, A.N. (1993). Redundancy reduction as a strategy for unsupervised learning. Neural Computation, 5, 289-304

Rhodes, G., Parkin, A.J., & Tremewan, T. (1993). Semantic priming and sensitivity in lexical decision. Journal of Experimental Psychology: Human Perception and Performance, 19, 154-165.

Robertson, S.P., Davis, E.F., Okabe, K. & Fitz-Randolf, D. (1990). Program comprehension beyond the line. In D. Diaper, D. Gilmore, G. Cockton & B. Shackel (Eds.), Human-Computer Interaction – INTERACT '90. Elsevier.

Schwartz, M.F., Marin, O.S.M. & Saffran, E.M. (1979). Dissociations of language function in dementia: A case study. Brain and Language, 7, 277-306.

Seidenberg, M.S. & McClleland, J.L. (1989). A distributed, developmental model of word recognition and naming. Psychological Review, 96, 523-568.

SELLEN, A.J., Buxton, W.A.S. & Arnott, J. (1992). Using spatial cues to improve desktop video conferencing. 8 minute videotape. Presented at CHI '92, Monterey, CA. Toronto: Dynamic Graphics Project, Computer Systems Research Institute, University of Toronto.

SHALLICE, T., Warrington, E.K., & McCarthy, R (1983). Reading without semantics. Quarterly Journal of Expermental Psychology, 35A, 111-138.

Tyler, L.K. (1992). Spoken Language Comprehension. Cambridge, Mass: MIT Press.

Van Orden, G. (1987). A ROWS is a ROSE: Spelling, sound and reading. Memory and Cognition, 15, 181-198.

Warrington, E.K. (1975). Selective impairment of semantic memory. Quarterly Journal of Experimental Psychology, 27, 635-657.

WRIGHT, P. (1977). Presenting technical information: A survey of research findings. Instructional Science, 6, 93-134.

WRIGHT, P. (1986). Phenomena, function and design: Does information make a difference. In D.J. Oborne (Ed.), Contemporary Ergonomics 1986 (pp.1-18) (Proceedings of the Ergonomics Society 1986 Annual Conference, Durham, England 8-11 April 1986). London: Taylor & Francis.

WRIGHT, P. (1988). Communicating with the user. In M. Heaton & M. Sinclair (Eds.), Designing End-user Interfaces (pp.123-129). (State of the Art Report 15:8). Maidenhead, Berks: Pergamon Infotech Ltd.

Collaborations

Bishop

UK based

Adams - Audiology, Manchester

Snowling - Psychology, Newcastle

Kaplan - Psychiatry, Newcastle

Plomin, Rutter, Simonoff - Institute of Psychiatry, London

Outside UK

Tallal - Behavioral Neuroscience, Rutgers University

Green

UK based

Gilmore - Psychology, Nottingham

Winder - Computer Science, UCL

Benyon, Petre - Educational Technology, Open University

Brna - Artificial Intelligence, Edinburgh

Richens - Architecture, Cambridge

Outside UK

Hoc - CNRS, Paris

Modugno, Myers - Computer Science, Carnegie-Mellon

Bellamy - Computer Science, IBM, NY

Norris

UK based

Briscoe - Computational Linguistics, Cambridge

Outside UK

Cutler, McQueen - Max Planck Institute for Psycholinguistic Research, Nijmegen

K Patterson

UK based

Hodges - Neurology, Cambridge

Butterworth, Wydell, Yin - Psychology, University College London

Tyler, Howard - Psychology, Birkbeck College, London

Wise, Price - MRC Cyclotron Unit, London

Outside UK

McClelland, Plaut - Psychology, Carnegie-Mellon

Seidenberg - Psychology, University of Southern California

NEUROPSYCHOLOGICAL REHABILITATION

A Baddeley 1.0, Emslie 1.08, Goodrich 0.75, Murre 0.38, Nimmo-Smith 0.75, Robertson 3.34, Wilson 3.0, Balleney (SO) 1.08, B Baddeley (ASO) 0.42, H Baddeley (HSO) 0.14, Bruce (SO) 0.17, Buxton (SO) 0.24, Evans (HSO) 2.5, Ivani-Chalian (SO) 0.42, Jolliffe (ASO) 0.25, Kolodny (SO) 0.06, Pike (SO) 0.17, Ridgeway

(HSO) 2.14, Shiel (HSO) 2.25, Toplis (ASO) 0.52, T Ward (HSO) 2.17

Total Person Years: Scientists 10.5; Research Support 12.4

Abstract

Objectives

The rehabilitation programme has sought to: (a) develop new theoretically-derived treatment techniques, (b) produce new theoretically-derived assessment procedures for identifying and monitoring cognitive deficits, (c) understand the natural history of recovery from brain injury, and (d) develop a theoretical framework for understanding the pattern of recovery of neuropsychological functioning.

Scientific progress and achievements over the past five years

In the area of memory and learning we have demonstrated tangible clinical benefits of applying principles of cognitive psychology to memory and learning deficits. Specifically, we have (a) shown that errorless learning is superior to trial-and-error learning for patients with severe memory problems; (b) shown that it is possible for patients in coma following traumatic head injury to learn simple tasks; (c) begun evaluating a new electronic memory aid; (d) developed assessment procedures for predicting everyday cognitive problems and for monitoring change over time; and (e) followed up a group of brain injured people in order to document the natural history of recovery from brain injury.

In the field of attention and cognitive control we have outlined a number of mechanisms by which recovery of neuropsychological function can take place, and demonstrated that improvement in unilateral neglect can be produced by capitalising on three of these mechanisms, namely: reducing inhibitory competition on the damaged right hemisphere by inducing limb activation on the left side of the body; maximising activation in the damaged hemisphere by synchronising activation in both body and extrapersonal space; increasing non-lateralised sustained attention. We have also developed new methods for tackling executive and sustained attention problems following closed head injury, and for assessing theoretically distinct types of attention.

Future plans for the next five years

We propose to maintain the balance between theoretically based experimental work and clinically driven therapeutic research. Building on the work of the past four years, we plan to improve function by incorporating principles of recovery, implementing new strategies to improve learning, and modify existing technologies to make them suitable for brain injured people. Specifically, in the field of memory and learning we plan to evaluate a new day rehabilitation unit for adults with non-progressive brain injury; (b) develop the work on errorless learning (in collaboration with Baddeley) by addressing some of the theoretical questions arising from earlier studies and by extending the clinical applications of this method; (c) continue with the evaluation of a new electronic memory aid; (d) continue to develop new assessment procedures for predicting performance in everyday life and monitoring change in clinical contexts; (e) extend understanding of the natural history of brain injury through following head injured people and people with Huntington's Disease; and (f) collaborate with Nimmo-Smith in developing methodologies to evaluate recovery and change over time.

In the area of attention and cognitive control we plan to work closely with Duncan, in applying the integrated competition hypothesis to recovery and rehabilitation. Specifically, we will: (a) model recovery of function in

several different deficits; (b) examine blood flow consequences of unilateral and bilateral limb activation; (c) further develop clinical strategies for treating neglect using limb activation; (d) examine the role of limb activation in anosognosia, global versus local processing, sustained attention and input versus output neglect; (e) evaluate further attentional control training and determine its effects on sustained and selective attention; (f) develop ways of improving sustained attention in unilateral neglect patients, including pharmacological methods; (g) examine frontal cerebral perfusion in good versus poor outcome closed head injury; (h) determine the blood flow consequences, if any, of goal neglect training; (i) develop theoretically-based clinical measures of aspects of attentional function, especially non-visual neglect.

Implications for improving health, health care and wealth creation

Our research has both direct and indirect implications for the care of brain injured people. New treatment methods developed by Wilson and Robertson have begun to influence clinical practice and are being implemented in rehabilitation programmes. Developing objective and theoretically sound assessment procedures that are also related to tasks met in everyday life has encouraged more effective identification and more relevant treatment of neuropsychological problems following brain injury. A clearer understanding of the natural history of recovery should result in better prediction of recovery that could in turn influence allocation of resources and thereby benefit the work of health economists. All our research has potential for reducing the cost of health care through improved diagnoses, better treatment and improved targeting of rehabilitation services. Finally, appropriate rehabilitation of the kind we are seeking to encourage by our work is likely to result in greater numbers of people returning to work and thus alleviating financial and other strains on health care and social services.

NEUROPSYCHOLOGICAL REHABILITATION OF MEMORY AND LEARNING DISORDERS*(Baddeley, Emslie, Wilson)*

Introduction

Neuropsychological rehabilitation is concerned with the assessment, treatment and natural recovery of brain injured people. The fundamental cognitive functions that are crucial in the relearning of new skills or compensatory strategies within rehabilitation are attention, memory and learning. In the APU's research into rehabilitation of these functions, Robertson has focused on attention (see his section in this programme of the report) and Wilson on memory and learning.

Essential to research into neuropsychological rehabilitation is access to patients requiring assessment and treatment so that the interface between research and practice is optimised. The past four years have been a transitional period for the Rehabilitation Research Group, as we have been attempting to set up a new programme while remaining outside a clinical setting. To compensate, group members have made use of prior contacts and have worked with more distant collaborators than would normally be regarded as ideal. Despite these difficulties, progress has been made in the major areas of assessment, treatment, and the natural history of recovery from brain injury. Further substantial progress is expected when the group has been relocated into a clinical setting.

A. Remediation of Disorders of Memory and Learning

Wilson and Robertson's earlier work has shown that methods found to enhance attention, memory and learning in non brain-injured people can also help those with deficits resulting from neurological insults. Effects for brain-injured individuals are, however, typically smaller, and there are limitations to the application of normal methods. There would appear to be two main approaches when treating people with memory and learning difficulties. One is to develop new teaching methods to enhance learning, and the other is to capitalise on and improve new technological equipment so that it is more suitable for use with brain injured people.

A1. Errorless Learning in the Rehabilitation of Memory Impaired People: Errorless learning is a teaching technique whereby people are prevented, as far as possible, from making mistakes while they are learning a new skill or acquiring new information. Instead of teaching by demonstration, which may involve the learner in trial-and-error, the experimenter/teacher presents the correct information or procedure in ways that minimise the possibility of erroneous responses.

In one group study (5.8), and several single case studies (5.51), it was demonstrated that people with severe memory disorders learn more successfully with an errorless learning strategy. People with poor episodic memory tend to rely upon implicit memory, which is poor at error elimination. Errorless learning has proved effective over a range of tasks (including learning names, learning new information, recognising pictures and programming an electronic aid), over a range of diagnostic groups (head injury, stroke, encephalitis and Korsakoff's syndrome) and over a range of periods post insult (from Post Traumatic Amnesia to 12 years post onset).

A2. Developing and Modifying New Technologies: Much of the work in memory rehabilitation involves teaching people to compensate for their impairments by employing aids such as diaries, tape recorders, filofaxes, electronic organisers, computers and so forth (5.15, 5.46, 5.76, 5.80). Work in this area of rehabilitation is complicated by the fact that remembering to use an aid is, in itself, a memory task. Thus brain injured people may forget to employ the aid; they may also experience problems in programming an aid or using it in a systematic and efficient manner. We have recently begun a collaboration with Hersh and Treadgold (California) to evaluate the effectiveness of NeuroPage, a simple and portable paging system with a screen that can be attached to a waist belt. NeuroPage uses an arrangement of micro-computers linked to a conventional computer memory and, by telephone, to a paging company. The scheduling of reminders or cues for each individual is entered into the computer and, from then on, no further interfacing is necessary. On the appropriate date and time the reminder is transmitted to the individual. All the individual needs to learn is to press one button. Preliminary results look encouraging.

A3. Learning in Coma: This work was undertaken with colleagues in Southampton (5.43). During an observational study of how patients with severe head injury recover functional skills, we noted that some patients could be prompted to remove a cloth placed over their face while still in coma. We designed three experiments, using backward chaining as the teaching method, to assess the possibility of learning in coma following severe head injury. The results, suggesting that comatose patients are capable of learning simple tasks, have both theoretical and practical relevance. Theoretical implications include the role of conscious awareness in learning and the processes by which comatose patients can learn. Practically, it might be possible to harness such learning in order to prevent some commonly observed complications arising from severe head injury, such as the adoption of postures that increase the likelihood of developing contractures.

A4. Providing a Resource for Clinicians and Relatives: This aspect has developed as a natural outcome of our reported work in the field of rehabilitation. Advice is given to several groups including professional bodies, clinical workers, medical personnel and relatives, and consists of information on the nature of rehabilitation, varieties of rehabilitation available and further contacts in the field. Workshops on rehabilitation have been presented in Britain and 14 other countries.

B. Assessment

B1. Developing Assessment Procedures for Predicting Performance in Everyday Life: Assessment under realistic conditions is important for predicting behaviour outside the laboratory or clinic, and also for its acceptability to both patient and therapist. One test which fulfils both these conditions is the Rivermead Behavioural Memory Test (Wilson, Cockburn & Baddeley, 1985). The RBMT has been shown to predict independence in daily life (5.44, 5.47) and is widely used by occupational and speech therapists as a tool to (i) predict how patients function in daily life, and (ii) monitor change over time. The test is used in 17 countries and has been translated into 11 languages. A children's version appeared in 1991 (5.55) and has been given to adults with Downs Syndrome (5.54) as a preliminary exploration into the suitability of the test for comparing Alzheimer's disease with the ageing effects seen in Downs Syndrome. We have also piloted an extended and more difficult version of the original RBMT in order to avoid ceiling effects when testing people with more subtle deficits (5.13).

A major area of current interest in research and rehabilitation is executive functioning and the deficits which appear following damage to the frontal lobes. Patients with DysExecutive Syndrome (DES) are likely to be impulsive and distractible, to have problems using feedback, and to behave inappropriately in social situations. They are among the most difficult of all brain injured patients to treat. Traditional tests used to assess problems in DES are unrepresentative of everyday tasks, and therefore sometimes yield normal scores in people who continue to experience problems in everyday life. Using theoretical models of Baddeley and Hitch (1974) and Shallice (1982), and in collaboration with Alderman (Northampton) and Burgess (London), we have designed a test battery to assess executive functioning. The Behavioural Assessment of Dysexecutive Syndrome (BADS, in preparation) contains tasks that are more representative of executive functioning in everyday life. Current work is funded by an EARHA/LORS grant. Emslie is currently collecting norms on the six subtests of the BADS together with a questionnaire which is given to patients and close relatives. Our eventual aim is to employ the test to help set rehabilitation goals. It could, for example, be used to evaluate the effectiveness of the Goal Neglect training described by Robertson in this report.

The BADS is primarily concerned with planning, organisation and problem solving, while the complementary Test of Everyday Attention (TEA) (5.86) focuses on various aspects of attention.

B2. Developing New Clinical Measures for use in Neurological Contexts: In addition to providing ecological assessment procedures, there is a need to develop new measures to assess impaired functions in brain injured people within the clinical context. One example is our attempt to develop a better measure of Post Traumatic Amnesia. PTA refers to the period following traumatic brain injury when the patient is no longer in coma but is confused, disorientated, suffers from retrograde amnesia and has difficulty learning new information. PTA is a useful index of the severity of brain injury and one of the best predictors of outcome, but it is rarely formally assessed. Although two tests of PTA are available (Levin et al., 1979; Shores et al., 1986), these do not distinguish between genuine PTA and more chronic memory impairment.

One study carried out with colleagues in Southampton (5.52) was designed to see how people in PTA differ from those with amnesic syndrome and from those with chronic memory impairment. All groups experienced memory problems, although those with the amnesic syndrome were the most severely impaired. People in PTA were poorer than the other groups on verbal fluency tasks, backward digit span, simple reaction time and accuracy of comprehension. We are now continuing the work on PTA with Boismeir (Neurosurgery, Addenbrooke's), supported by a grant from EARHA. Our concern is to assess and characterise the pattern of recovery from PTA. The analyses are being conducted with the help of Nimmo-Smith (APU).

Prospective memory, remembering to perform a pre-specified action, is another function that is subject to impairment following brain damage and is of interest to both theorists and practitioners. To date, the only published test to include standardised measures of prospective memory is the RBMT. Evans, Wilson and Baddeley are in the process of developing a test of prospective memory in which subjects read a story and while doing so are supplied with instructions, inserted in the story, relating to actions they have to remember to perform at a later point. The test is highly sensitive to the effects of age.

B3. Advising on Assessment Measures for Clinical Researchers: A number of other centres have sought our advice on the development of effective assessment procedures for their studies. Wilson and Baddeley are on the Advisory Committee for the Department of Health National Brain Injury Study, which approached us with a request to provide additional sensitive measures to assess the effectiveness of rehabilitation programmes. Other requests for advice on neuropsychological measurement include one concerned with a multicentre drug study by Wellcome, which attempts to prevent some of the undesirable consequences of head injury that develop immediately after insult. Wilson is also consultant to a study examining the effects of HIV infection in homosexual men (5.26), and in people with haemophilia. Finally, we provide a resource service for other professionals as to the most appropriate tests to use in specific circumstances.

C. The Natural History of Brain Injury

This work includes studies of the natural history of recovery of non-progressive disorders and a specific examination of the pattern of decline in Huntington's disease. Knowledge of the natural history of a neurological condition is important for understanding a disease and its pattern of recovery; such studies must involve longitudinal approaches with repeated measures over time. Data from these may present statistical and methodological challenges which we are addressing with the help of Nimmo-Smith (APU).

C1. Long-Term Follow-Up of Brain Injured People 5-15 Years Post Insult: Since 1988 Wilson has been engaged on a series of follow-up studies of patients first seen between the years 1979 and 1986. The main aims were: (i) to see how neuropsychological functioning changes over time, (ii) to collect information about long-term vocational and social outcomes for brain injured people, (iii) to identify the main compensatory strategies used by people with brain injury, and (iv) to identify characteristics which lead to poor or good outcome. A subsidiary purpose was to identify patients with theoretically important neuropsychological syndromes.

The first follow-up study was of 54 people referred for memory therapy between the years 1979-1985 (5.44, 5.46). Most subjects were using more compensatory strategies at follow-up than at the end of rehabilitation; 30 per cent had shown noticeable improvement in their scores on a standardised memory test; 36 per cent were in paid employment; and 20 per cent were living in institutional care.

The second study looked at a group of seven people originally referred for remediation of acquired disorders of reading (5.49). The main finding here was that, despite some significant gains during rehabilitation, subjects showed little further improvement following discharge, and only three subjects read for pleasure.

The third study is currently following people with very severe intellectual impairments. These were operationally defined as initially untestable on standardised neuropsychological tests for adults, and were originally assessed on tests for children with learning difficulties. A subgroup of patients with anoxic damage will be written up as a separate group due to their significant visuo-spatial and visuo-practic difficulties.

A number of patients with theoretically important neuropsychological syndromes have been identified; the long-term follow-up research has enabled us to isolate and assess syndromes that were previously difficult to detect because of widespread damage in the early stages after insult (5.50, 5.53, 5.60).

C2. The Use of Functionally Relevant Assessment Procedures in Predicting Long-Term Outcome after Severe Head Injury (Wilson, McLellan, Evans, Pickard): In a previous project funded by the MRC (Wilson, McLellan & Campbell, 1987) we developed a set of scales to assess recovery of cognition, awareness, communication and motor skills (5.84). These scales, based on the assessment of 88 patients, have proved useful in identifying patterns of recovery of function in each of the skill areas (5.21). In the present project, we are testing the sensitivity of the scales for predicting outcome three years later. In collaboration with Shiel (Southampton), we have traced and reassessed 40 of the original sample. Each subject has been reassessed on tests of neuropsychological functioning, motor skills, activities of daily living and social functioning. We are at present analysing results with the help of Nimmo-Smith (APU).

C3. Change over time in People with Huntington's Disease (HD): In collaboration with Ward and Shiel (Southampton) we are seeing a group of people who attended the genetics clinic for screening for HD. All subjects are being followed longitudinally to see how memory and executive function change.

FUTURE PROPOSALS

Introduction: Neuropsychological Rehabilitation of Brain Injured People with Memory and Learning Disorders

This programme of research is concerned with the development and evaluation of new rehabilitation methods. Successful rehabilitation depends on combining an understanding of the patient's deficits with appropriate treatment and reintegration into the community. Because of recent changes in the National Health Service, our neuropsychological rehabilitation programme has had to proceed in rather a piecemeal fashion. This looks set to change, however, with (a) the Rehabilitation Research Group's move to Addenbrooke's Hospital later this year, and (b) the strong possibility of a new neuropsychological rehabilitation day unit to be set up by Lifespan, the NHS Trust responsible for community care, with Wilson as scientific director. Such a unit would incorporate the best currently available treatment, would encourage the development of new treatments as well as new ways of evaluating these, and would become a unique establishment for bridging MRC and NHS contributions to treatment research. Proposed research for the next five years would be centred largely around the new unit and the new development at Addenbrooke's Hospital. It would build on the work of the past four years and would also include evaluation of the new service's efficacy and cost effectiveness at a broader level.

A. Evaluation of Treatment Programmes and Therapeutic Strategies

A1. Evaluation of a New Neuropsychological Rehabilitation Unit: Lifespan Trust is planning to open a day rehabilitation unit for adults with non-progressive brain injury. The unit would cater for 15 patients at any one time, each of whom would attend five days a week for approximately four months. All patients would receive both individual and group sessions, and the programme would be modelled on the successful centres that have been operating for several years in New York, Phoenix and Copenhagen. Such a unit, staffed by carefully selected therapists, would offer a unique opportunity for the development and evaluation of new treatment procedures. It would provide access to a wide range of potentially interesting neuropsychological patients who would be available for a sufficiently long time to make detailed single case studies possible. It would thus facilitate the basic research of the APU as well as provide a mechanism whereby such research could be applied within a clinical context, thereby encouraging its transfer to more widespread use within the Health Service. The opportunity exists to evaluate the efficacy and cost effectiveness at a more general and comprehensive level through collaboration with Stilwell (Warwick). Currently in charge of the Department of Health National Brain Injury Study, Stilwell has agreed to collaborate on the design of this study and would provide access to the National Databank for the provision of control data.

A2. Errorless Learning: Earlier work demonstrated the superiority of errorless over errorful learning for people with severe memory disorders (5.8, 5.51, 5.74). While it is already clear that errorless learning can be a very effective way of teaching amnesic patients, we still have a relatively limited understanding of its theoretical underpinning. It is not clear, for example, whether the effect depends entirely upon the implicit component of learning. This issue has substantial implications for the range of tasks to which the technique might be applied, and to the question of whether it could usefully be combined with principles that optimise explicit memory, such as the utilisation of richer and deeper encoding. One feature of the studies carried out so far is the tendency for amnesic patients to show marked forgetting over relatively brief delays once the errorless testing method has been abandoned. This raises practical questions such as the optimal degree of over-learning, and also theoretical issues such as the nature of the forgetting. Finally, because the phenomenon suggests the possibility that implicit and explicit modes of learning may be differentially subject to interference effects, it has substantial implications for the general issue of the role of interference in learning and remembering. This aspect of the work will be pursued in a collaboration between Wilson and Baddeley and will form part of a grant proposal by Baddeley.

A3. Developing New Technologies: The preliminary encouraging results from the NeuroPage project will be pursued more systematically. We (Wilson, Evans, Malinek) are seeking funding from the NHS Research and Development Fund, and will continue the collaboration with Hersh and Treadgold (California), the designers of NeuroPage. A combined single case design (using a multiple baseline across subjects) and a two-group design is proposed.

A4. Remediation of Semantic Memory Disorders: In an earlier study (5.60) it was noted that semantic memory problems are not uncommon in brain injured patients. Some of these patients have severe episodic as well as semantic memory deficits whereas others have minimal episodic memory involvement. The question arises as to whether this group of people can relearn semantic concepts. Indeed, it might be possible to reteach some semantic information even to those with severe amnesia. Systematic attempts at remediation of semantic memory disorders might shed light on some controversial theoretical issues, including the distinction between deficits of storage vs. access, and whether this distinction might be systematically related to the aetiology of semantic memory disorders.

We propose to investigate the possibility of reteaching semantic information to patients with (i) reasonably intact episodic memory functioning, and (ii) severely impaired episodic memory functioning. We shall attempt to determine whether recent findings of Snowden, Griffiths and Neary (1994) apply to our patients. Snowden et al. demonstrated that, in patients with semantic dementia (i.e. those with progressive disorders), personally relevant semantic information was markedly better preserved than less personally meaningful information. Because of the relative scarcity of suitable local patients, this study will make use of single case experimental designs.

B. Assessment

B1. Development of Assessment Procedures for Predicting Performance in Everyday Life: As part of our aim to provide clinically acceptable tests that predict performance in daily life, we will continue to work on the tests described in the Report for 1990-1994. We need to demonstrate the suitability of the extended version of the Rivermead Behavioural Memory Test (5.13) for patients with very mild memory deficits. The Behavioural Assessment of the Dysexecutive Syndrome will probably be ready for publication early in 1995, following studies with brain injured people and people with schizophrenia (in collaboration with McKenna, Cambridge). The BADS is likely to prove useful as an outcome measure for treatment of people with deficits of attention, planning and problem solving. We plan to utilise existing links with colleagues in Europe to demonstrate this aspect, and to collaborate with Robertson and Duncan in their study of goal neglect (see their sections of this report).

We also plan to develop some preliminary work on a more qualitative prospective memory test designed to predict use of external memory aids in daily life, which can be used to see where and how compensatory failures occur. It could also be used as an outcome measure to evaluate memory rehabilitation programmes. Chiapello and Prigatano (Phoenix, Arizona) are collaborating on this project.

B2. Developing New Clinical Measures for Use in Neurological Contexts: The analyses of the Post Traumatic Amnesia study should be completed by late summer 1994. The next step will be to select the most sensitive tests from the original battery as a brief assessment tool to identify those patients who are in or out of PTA, in order to help with questions about discharge or referral to rehabilitation. In collaboration with Pickard (Cambridge) and others in Neurosurgery, we will also determine whether the new brief battery is appropriate for those with a mild head injury and a shorter PTA. In collaboration with Robertson and Murre, we intend to develop a neuropsychological model of PTA based on attentional and executive processes (see Robertson's section of this report).

We described above the pilot study of a prospective memory test involving reading a story in which several instructions are embedded. This test is to be modified for use as a clinical and research tool. The tasks that subjects are requested to perform have been chosen to tap different aspects of prospective memory, namely (i) time- versus event-based tasks, (ii) pulse versus "step" tasks, (iii) simple versus complicated tasks, and (iv) habitual versus episodic tasks. In addition, there will be a manipulation involving the number of tasks subjects have to remember at any one time. We know from the pilot work that the test is sensitive to age-related differences. We now plan to develop the test so that it is useful for assessing prospective memory functioning in patients with brain injury. We will also evaluate the relative effectiveness of computer versus paper-and-pencil versions, look at parallel-form reliability within each version, and use the new test to examine the relationship between prospective memory, retrospective memory, and other cognitive functions. Finally, the extent to which prospective memory failures contribute to the everyday problems of brain injured people will be examined.

C. Natural History of Brain Injury

C1. Reliability and Validity of Functionally Relevant Assessment Scales for Severely Head Injured Patients: In a previous study (5.21, 5.84), we devised scales to monitor the improvement of cognitive skills, social behaviour, motor ability and self care in recovery from severe head injury. The main advantage of these scales is that they rely on behavioural observations of skills used in everyday life, and therefore have implications for care and rehabilitation of head injured people. The next steps, to be conducted in collaboration with McLellan and Shiel in Southampton, are (i) to ensure that the scales are reliable and valid, and (ii) to determine whether the scales can be used to identify goals for treatment.

C2. Change Over Time in People with Huntington's Disease: In collaboration with Ward and Shiel (Southampton) and Kopelman (London), Wilson (APU) is seeking funding to employ a full-time assistant to (i) investigate the way in which memory, intelligence and other functions are affected in the early stages of HD, and (ii) follow up the original sample to clarify the manner of dissolution of different cognitive functions. In the long term this should lead to improved counselling for patients and relatives and the development of more appropriate management and rehabilitation strategies for families with HD members.

C3. Development of Methodologies to Evaluate Recovery and Change Over Time: Outcome studies present a number of methodological challenges. For example, they may include important data obtained through complicated multiple repeated observation schedules at irregular times (e.g. 5.84) but with significant amounts of missing data, making analysis problematic. Nimmo-Smith, in collaboration with Wilson, Evans, Emslie and Baddeley, proposes to capitalise on and adapt the growing body of techniques for analysing 'messy data' from various fields within social science and health care. Applying these methods to the modelling and analysis of clinically obtained neurological data will enable the evaluation of trends and interventions as well as the relevance of a variety of factors in the presence of many covariates. In addition, results are likely to help improve designs for outcome studies.

NEUROPSYCHOLOGICAL REHABILITATION OF ATTENTION AND ASSOCIATED DISORDERS *(Goodrich, Murre, Robertson)*

Introduction

Attention is not a unitary phenomenon, and recent PET and other studies have suggested a set of possible brain circuits which may be responsible for different supramodal attentional processes in the brain. Many types of brain damage cause attentional problems, and attention may have a privileged role in recovery of function following damage to the brain (5.68). Attention is therefore of great theoretical and clinical importance, and the aims of our current research are to develop methods of assessing different types of attention, to determine the nature of these mechanisms and their interactions, and to find viable clinical methods of treating these disorders. This report covers work carried out partly in the Neuropsychological Rehabilitation Programme of the Unit's work and partly in the Attention and Cognitive Control Programme. The overlap is however substantial, and therefore the entire programme of work is presented under the Neuropsychological Rehabilitation Programme.

A. A Theoretical Framework for Attention and for Recovery of Function *(Robertson, Murre, Ward, Ridgeway)*

A1. A Theoretical Framework for Attention Disorders: This work dovetails with Duncan's (see his section of this report, in Attention and Cognitive Control). We concur with his view that selection takes place through a process of competition within the visual and other modalities, via mechanisms such as the attentional template. However, the thrust of our research is to explore the possible existence of additional supramodal attentional control systems which come in to play when tasks are not automatic or overly simple.

PET scan research suggests the existence of several different attentional systems in the brain which have specialised control functions independent of any particular sensory modality. These include a system for selection, a system for sustained attention, and an orientation system whose role is to shift attention in space. Standardised clinical instruments to measure these different aspects of attention do not yet exist, and so the Test of Everyday Attention (TEA) (5.86) was developed, based as much as possible on familiar everyday materials such as maps and telephone directories. Factor analysis of data from 150 normals in the standardisation sample produced a factor structure which was indeed strongly related to the theory outlined above. Assessment in a group of 120 CVA patients found highly significant correlations between several of our measures of attention and functional status in everyday life, suggesting a clinical utility of the test in addition to its theoretical coherence. We have shown also that recovery of physical independence between two and eight months post-stroke is strongly predicted by our two-month TEA attention measures. Furthermore, we obtained evidence -- previously unreported in the literature on closed head injury -- for a deficit in sustained attention, and found the TEA to be very sensitive to the effects of closed head injury.

This research has close links with the work of Wilson on the Behavioural Assessment of Dysexecutive Syndrome (BADS) Test (see Wilson's section in this programme).

A2. A Theoretical Framework for Recovery of Neuropsychological Function: This is a recent area of collaborative work between Robertson and Murre in which we have attempted to develop a theoretical framework for recovery of function. The framework is partly designed to account for the experimental work on neglect and attention outlined below, and partly informed by connectionist models of neural reorganisation following localised lesions. In this framework, we exclude those compensatory mechanisms which Luria and others have proposed to underlie much recovery of function, and have instead concentrated on processes which may allow more intrinsic recovery of function in the lesioned modules themselves. Our model proposes four possible mechanisms of recovery of function: a) Increasing activation of malfunctioning circuits/representations by reducing competition from adequately functioning circuits/representations; b) increasing integration of malfunctioning circuits/representations to produce a summation of activation; c) improving performance of malfunctioning circuits by increasing arousal/sustained attention; d) improving strategic control over behaviour through implementing strategies for selecting relevant goals, as well as for rapidly encoding and retrieving these goals. These possible mechanisms provide the framework within which the past and future research programmes are formulated.

B. Improving Function by Reducing Competition from Non-impaired Circuits *(Robertson, Goodrich)*

Much brain activity is competitive, and hence a circuit weakened by damage is at risk of even greater impairment by inhibition from competitor circuits. Such competition may be especially likely following unilateral brain damage in stroke, when the undamaged hemisphere can inhibit the damaged hemisphere's function via connections across the corpus callosum.

B1. Experimental Studies of Limb Activation in Unilateral Neglect: In patients with inattention for the left side of space, left hand and left leg movements can significantly reduce neglect on reading and cancellation tasks (5.2, 5.36). Neglect patients' tendency to veer to the right when walking can also be corrected by having them perform left hand movements while moving (5.41). Our explanation of these findings is that the left limb movements increase activation of the damaged hemisphere and thereby reduce competition from the intact hemisphere. The close connection between action and attention in the primate brain suggests that the limb movements may activate linked attention circuits as well as motor circuits in the damaged hemisphere, thus leading to increased activation. A further study (5.39) showed that the beneficial effects of left hand movements could be eliminated when simultaneous identical right hand movements were made. This finding, explicable in terms of motor extinction, has considerable implications for the way in which physiotherapy is carried out with neglect patients. These results (a) can be integrated into the theoretical model of competition and extinction within attention systems proposed by Duncan (this report); and (b) find some parallels in the work of Wing on biofeedback methods for balance training in stroke patients (described in the Perception and Action programme of this report).

B2. Clinical Implementation of Limb Activation in the Treatment of Unilateral Neglect: The short-term experimental effects of limb activation on neglect were incorporated into a clinical treatment regime, using an electronic device, "the Neglect Alert Device". This device emits randomly spaced sounds that are terminated by activating switches with movements by the affected side of the body. The aim of this treatment is to increase left limb activation in a variety of everyday situations. Three single case studies showed enduring clinical improvements, both on neuropsychological tests and in everyday life function, as a result of this procedure (5.40). The clinical effect has subsequently been replicated by a team not involved in the original development of the treatment procedure.

C. Improving Function by Summating Activation of Mutually-Facilitatory Circuits (Robertson, Goodrich)

While some circuits are mutually inhibitory and competitive, others are facilitatory, such that synchronous activation may produce a summation of activation sufficient to yield significant improvements in function. Our research suggests that attention circuits for different spatial arenas have a facilitatory relationship. The work of Rizzolatti and others has shown that space can be divided into three independent yet related arenas: body space, external reaching space, and external far/locomotor space. Different brain circuits control attention to these different spatial areas, and lesion studies reveal dissociations between all of these spatial systems, with some patients for example showing unilateral neglect within body space but not external space, etc. We hypothesised that synchronous activation of these overlapping circuits might lead to improvements in unilateral neglect. Goodrich (see her section in the programme on Attention and Cognitive Control) has also investigated the possibility that, in the sensory domain, improved detection of neglected stimuli may occur when additional sensory modalities are used to signal the presence of these stimuli.

C1. Personal and Extrapersonal Space in Limb Activation: A beneficial effect on unilateral left neglect was produced by left hand movements made in left hemispace, but not by either left hand movements in right hemispace or right hand movements in left hemispace. Passive movements of the left hand in left space also had no impact on neglect, and we concluded that it was the synchronised activation of the left representational fields for both personal and reaching space which resulted in combined activation sufficient to improve attention to the neglected side (5.36, 5.37, 5.39).

C2. Gripping versus Pointing in Unilateral Neglect: The nature of the response made to the left side of space may affect neglect, if certain responses activate additional motor circuits. In collaboration with Hood (University of Cambridge), we studied neglect patients on tasks involving either pointing to or lifting of metal batons. Pointing to the perceived centre of the baton produced relatively more neglect than a movement towards the baton with the intention to pick it up. This suggests that the activation of motor circuits related to planning complex movements improves attention to the neglected side, possibly via mechanisms similar to those involved in the limb activation studies described above.

D. Improving Function by Increasing Arousal/Sustained Attention

Arousal and sustained attention are central to recovery of function following brain injury, and hence improvement of sustained attention deficits is potentially important for rehabilitation. The sustained attention system may have a particularly direct modulating role on the posterior attention orientation system implicated in neglect, possibly via the noradrenaline pathways which are reported to be more strongly represented in the right hemisphere of the brain. Increasing arousal and sustained attention may therefore have both general effects on neuropsychological performance and specific modulating effects on unilateral neglect. This argument allows us to predict both deterioration in neglect in conditions where sustained attention is impaired, and improvements in neglect under conditions where it is enhanced.

D1. Attentional Load and Unilateral Neglect: We showed that neglect could be worsened by purely auditory-verbal attentional manipulations (5.34). We also found support for the view that the lateralised attentional disorders characteristic of neglect were strongly influenced by non-lateralised attentional factors (5.66): For instance, loading auditory-verbal working memory by a random number generation task produced significant greater unilateral neglect than a control condition (5.34). The mechanism for this interference may be degradation of the sustained attention required for the lateralised scanning tasks caused by the load on working memory. Further evidence for a strong role of non-lateralised attention in unilateral neglect comes from our study showing that left neglect patients at times show paradoxical right neglect, due to the partial implementation of a compensatory leftward scanning strategy in the context of impaired non-lateralised attention (5.35).

D2. Interactions between Sustained Attention and Unilateral Neglect: Degrading sustained attention may worsen neglect, but can neglect be improved by enhancing sustained attention? In a study carried out with colleagues in Stockholm and Southampton, eight patients with unilateral neglect were trained to improve their sustained attention with a self-instructional procedure which capitalises on intact phasic arousal, i.e., alerting in response to salient or novel external stimuli. The rationale of the training is that this intact capacity for exogenously oriented attention can be harnessed to bring the phasic response under endogenous, verbal control. Using some of the measures developed for the Test of Everyday Attention, we obtained statistically significant improvements in both unilateral neglect and sustained attention as a result of this training, with duration of the effects ranging from 24 hours to seven days (5.59) . This finding provides strong, counter-intuitive evidence for an intimate link between two of the attentional subsystems described above, with therapeutically promising consequences.

D3. Attentional Control Training: Attentional control training involves training a subject to detect when attention has strayed from a target stimulus -- the breath -- and to redeploy attention back to the target. We have applied this method, which Teasdale (see his section in the Cognition and Emotion programme of this report) has been exploring with recovered depressives, to patients approximately one year after closed head injury. In a randomised control pilot study, we found significantly greater reductions in problems of self reported memory, attention and mood in the trained over the untrained group. These beneficial effects may arise because of improved sustained attention, reduction in attention-occupying distressing thoughts, or indeed both of these. The advantage of this method of training sustained attention is that the metacognitive training is both unobtrusive and intrinsically rewarding, and may be more widely generalisable than material-specific attention-training procedures which we have developed (5.57)

E. Improving Function Through Enhanced Goal Encoding and Goal Management *(Robertson, Duncan)*

Attention overlaps considerably with the concept of executive function, and Duncan has argued that the ability to encode relevant behaviour goals is central to executive function. People who fail to do this may show "goal neglect", and this impairment may arise because of a failure actively to encode or a difficulty in maintaining relevant goals in working memory, in the face of competition from other possible goals.

E1. Goal Neglect Training: We have begun to pilot a procedure for reducing goal neglect in closed head injury patients with poor executive control. The training involves teaching a general problem-solving algorithm, together with mnemonic and other strategies aimed at increasing the efficiency of goal encoding in working memory. So far, pilot single-case data on three cases are available, but the series is not yet complete.

FUTURE PROPOSALS

Introduction: Neuropsychological Rehabilitation of Attention and Associated Disorders

We propose in the next five years to maintain the balance between theoretically-based experimental work and clinically-driven therapeutic research. It is in the nature of rehabilitation research that tractable clinical effects must at times precede the experimental analyses and theoretical justification of these effects. The two approaches must go hand in hand if neuropsychological rehabilitation is to develop as a scientifically based discipline.

Our research will concentrate on trying to improve function, experimentally in the short term as well as therapeutically in the medium term, based on the principles of recovery described above, namely a) competition/extinction, b) integration, c) arousal and c) executive control. These principles will be applied to the following clinical disorders of attention: unilateral neglect; dysexecutive syndrome following frontal lobe lesions; sustained attention deficits following right hemisphere lesions; disorders of selective attention, attentional switching and divided attention following closed head injury and other lesions.

Finally, there is a strong overlap between this clinically-based research programme and the experimental and physiological analyses of visual attention and executive functions described by Duncan (see his section of this report), and we plan to integrate our future work with Duncan's research programme wherever possible. As shown already in our work on both limb activation and goal neglect training, each programme stands to benefit substantially from collaboration with the other.

A. A Theoretical Framework for Attention and for Recovery of Function *(Robertson, Murre, Wilson, Wing, Nimmo-Smith)*

A1. A Theoretical Framework for Attention Disorders: The attentional measures and concepts developed in the previous programme will be applied, in collaboration with Wilson, to the phenomenon of post-traumatic amnesia (PTA). Wilson (see her section of this programme) has shown attention-like measures to be the best discriminators between patients in PTA on the one hand and amnesic patients on the other. The aim will be to try to develop a model of post-traumatic amnesia based on attentional and memory processes.

A2. A Theoretical Framework for Recovery of Neuropsychological Function: We will further develop the model of recovery of function outlined above, and will apply this model to patterns of recovery in PTA as well as in unilateral neglect and other attentional disorders. Furthermore, Robertson, Wing and Nimmo-Smith will compare motor learning with the left and right hands in unilaterally lesioned stroke patients, with a view to elucidating the determinants of learning in neuropsychological recovery. These data will be examined in the light of the theoretical concepts devised by Robertson and Murre.

B. Improving Function by Reducing Competition from Non-impaired Circuits *(Robertson, Duncan, Goodrich)*

B1. Experimental Studies of Limb Activation in Unilateral Neglect: Assuming that PET and fMRI facilities at Cambridge become available, we plan to investigate the influence of unilateral and bilateral limb activation on cerebral blood flow (in collaboration with Duncan). We predict that unilateral left hand activation (in left neglect) will produce blood flow increases in areas beyond those usually responsible for simple motor movements, and more particularly in the right fronto-parietal cortex. We further predict that bilateral hand activation will abolish these fronto-parietal bloodflow increases, because of competitive inhibition from the intact hemisphere.

B2. Clinical Implementation of Limb Activation in the Treatment of Unilateral Neglect: Resources permitting, we propose to conduct a clinical trial of a new version of the Neglect Alert Device (in collaboration with McMillan, Wolfson Rehabilitation Centre, London) in order to determine the clinical viability and utility of the limb activation procedure developed in the previous programme. As part of the same collaboration, we hope to carry out a larger and better trial of attentional control training in closed head injury.

B3. Competition-Reduction Applied to Other Attentional Disorders: We would like to extend the competition/inhibition hypothesis to other types of disorder, such as the 'global' (as compared to 'local') processing which appears to be particularly impaired following some right hemisphere strokes. Duncan's group have suggested the possibility of competitive imbalance between global and local processing systems arising in the context of unilateral brain lesions. If this is the case, then it is reasonable to hypothesise that -- if limb activation influences lateralised attention in neglect -- it may also have a spreading effect on closely linked structures in right parietal cortex possibly specialised for global processing. We will therefore assess whether left hand movements improve global versus local processing in right lesioned patients. Similarly, we will examine whether right hand movements, by activating left parietal circuits, improve local processing in left lesioned patients.

We also plan to study whether left limb movements improve sustained attention in right lesioned stroke patients, given a right fronto-parietal specialisation for sustained attention, and will extend this paradigm to related disorders with a strong lateral bias such as anosognosia (lack of awareness) for plegia and neglect. The latter are particularly associated with right hemisphere lesions affecting the parietal lobes; hence if limb activation does indeed increase parietal function, then some improvement in sustained attention may be expected. These experiments address both conceptual issues, such as the extent to which impaired function is attributable to competitive inhibition by parallel circuits in the undamaged hemisphere, and issues of treatment, such as the extent to which extinction can be overcome to produce gains in functional performance.

Finally, we also plan to continue our research on walking trajectory, by studying blindfolded walking in normal subjects with and without hand movements. A preliminary study (5.41) demonstrated rightward veering in normal subjects under normal conditions, and very recent data suggest a much stronger effect under blindfold conditions, with a possible role for hand movements even in normal individuals. Further studies would allow us to determine whether activation effects comparable to those found in unilateral neglect are applicable to normal brain function.

Inhibition of weak representations by strong ones can also occur beyond the realm of lateralised visuo-spatial attention. Failures of selective attention in closed head injury and frontal lesions, for instance, may be described in terms of inhibition of the to-be-selected stimulus (by a competing stimulus) as the activation of the former declines in strength with habituation. This may underlie the commonly reported problem, in patients with head injury, of having difficulty following a single voice against a background of other voices, or similar difficulties in the visual modality.

We will explore the possibility of reducing competition/inhibition from to-be-ignored stimuli in at least two ways. Firstly, we will evaluate the effects of the attentional control training which has been piloted in closed head injury with promising results. Once head-injured subjects have learned to carry out the mindfulness procedure, does this result in reduced distraction from irrelevant stimuli in an auditory selection task, compared to a control condition? Secondly, we will train subjects to encode different features of a to-be-selected stimulus as a means of attempting to increase its overall activation and hence reduce competition from irrelevant stimuli. For instance, in listening to a voice among other voices, the subject would be trained consciously to encode pitch and timbre using idiosyncratic mnemonic labels (e.g. soft/harsh; shrill/growling). Parallel studies in the visual modality would attempt to improve selection by the simultaneous encoding of a number of dimensions (size, colour, shape etc.).

C. Improving Function by Summating Activation of Mutually-Facilitatory Circuits *(Robertson, Duncan)*

C1. Personal and Extrapersonal Space in Limb Activation: We have suggested in the previous research programme that threshold effects in reducing neglect can be obtained when mutually facilitatory but independent circuits/representations for personal and extrapersonal space are simultaneously activated. We plan further evaluation of limb activation effects under PET/fMRI, predicting that a threshold increase in activation should be observed for left limb movements made in left extrapersonal space but not for either left hand movements in right extrapersonal space, or right hand movements in left extrapersonal space.

C2. Gripping versus Pointing in Unilateral Neglect: Can this principle of synchronised activation be found in other cognitive processes? We have already established that planning to lift a metal rod evokes less neglect (as measured by deviation from centre) than pointing to its centre, suggesting that when visual attention to an area in space is combined with planning of a motor response to that same area, activation in the damaged hemisphere may be sufficient to reduce competition from the intact hemisphere. It may be however that both types of dual-system activation are purely features of impairment in a system for planning motor actions to contralesional space, and do not affect attention to stimuli in that area of space. Unilateral left neglect is now known to fractionate into "output" neglect (a difficulty in making responses to the left side of space) and an "input" neglect (a difficulty in attending to stimuli on the left side of space). Most tests of neglect confound these two categories, by requiring both attention to, and responses to, stimuli on the left side. We therefore propose to repeat previous experiments on left and right limb activation in left and right hemispace with neglect patients showing either type of neglect. If limb activation is effective only for "output" neglect, then this has both important clinical implications for targeting limb activation training and important theoretical implications for competition and inhibition between and within hemispheres.

C3. Clinical Implementation of Summation of Activation Methods: If the above experiments indeed show a differential responsivity to limb activation of the two types of neglect, then a series of single case studies will be carried out with each type of patient: limb activation training with the output neglect patients, and a training procedure which attempts to strengthen attentional representations of objects in the neglected field with the input neglect patients. If no differential effects are found, then clinical studies will focus on further evaluation and implementation of the limb activation procedures for routine clinical use.

D. Improving Function by Increasing Arousal/Sustained Attention *(Robertson, Duncan, Ridgeway)*

Robertson has received support (£28K over 12 months) to pursue the Attentional Control Training with stroke patients.

D2. Interactions between Sustained Attention and Unilateral Neglect: Strong connections between sustained attention and unilateral neglect were documented previously (5.59) . We propose to examine the effects of sustained attention manipulations on processes related to unilateral inattention, including anosognosia/awareness problems, global/local processing, selective attention, divided attention and attentional switching. In other words, does sustained attention supply an additional and general "resource" to all other attentional systems, or only to the posterior attention (orientation) system?

We also plan to examine the effects of certain nor-adrenergic agonists on neglect, given their action on the norepinephrine system implicated in sustained attention/arousal. This depends on obtaining the necessary funding. We also plan to examine experimentally the nature and determinants of sustained attention deficits in closed head injury and stroke, contrasting performance in conditions of high and low distraction in both auditory and visual modalities, in order to determine the relative roles of distraction, fatigue and decline in self-monitoring/self-alerting over time. Finally, we plan to measure blood flow changes using PET and fMRI during sustained attention activation procedures, as well as looking at the enduring effects on cerebral bloodflow of these activation procedures over time.

D3. Attentional Control Training: In section B3 above, we outlined proposed experimental work on Attentional Control Training. We have funding from the Stroke Association to extend the clinical evaluation of Attentional Control Training to a population of stroke patients.

D4. Psychophysiological Markers of Sustained Attention: We will attempt to develop psychophysiological markers of sustained attention during continuous performance tasks, with a view to using these markers as outcome measures in subsequent treatment studies.

D5. Clinical Implementation of Sustained Attention Training: We plan to try to develop and evaluate a procedure for implementing the sustained attention training procedure carried out in the previous programme (5.59) . This may involve a portable apparatus which delivers arousing sensory stimulation on a random basis, connected with a tape recorder which delivers appropriate self-instructions in the patient's own voice. We plan to evaluate sustained attention training delivered by this or similar methods using single-case designs.

E. Improving Function Through Enhanced Goal Encoding and Goal Management

E1. Goal Neglect Training: The main focus of this work is clinical, as it is closely tied in with the experimental and theoretical work of Duncan. However, PET and fMRI studies of components of the training strategy will be carried out, to see whether active goal encoding produces increased frontal blood flow during problem solving in frontally lesioned patients. Furthermore, closed head injury patients with poor and good functional status at one year post head injury will be compared in terms of cerebral perfusion, and we predict low frontal perfusion in the low functional status group. We have already carried out pilot work on a goal neglect training strategy, and are currently performing SPECT scans pre- and post-training, as well as neuropsychological testing. If the pilot studies continue to be successful, we plan a controlled trial of goal neglect training for closed head injury patients with MRI-defined frontal lesions. We may also carry out a similar study on elderly normals with disproportionately low performance on frontal tests.

PUBLICATIONS

Edited Books

5.1.* BADDELEY, A.D., WILSON, B.A. & WATTS, F.N. (Eds.) (in press). Handbook of Memory Disorders. Chichester: John Wiley & Sons.

5.2. ROBERTSON, I.H. & Marshall, J. (Eds.). (1993). Unilateral Neglect: Clinical and Experimental Studies. Hove, Sussex: Lawrence Erlbaum Associates.

5.3. Stachowiak, F.J., De Bleser, R., Deloche, G., Kaschel, R., Kremin, H., North, P., Pizzamiglio, L., ROBERTSON, I. & WILSON, B. (Eds.). (1993). Developments in the Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European Concerted Action. Tübingen: Gunter Narr Verlag.

5.4. WILSON, B.A. & Moffat, N. (Eds.). (1992). Clinical Management of Memory Problems (Second edition). London: Chapman & Hall.

Refereed Articles

5.5. Aldrich, F.K. & WILSON, B.A. (1991). Rivermead Behavioural Memory Test for Children (RBMT-C): A preliminary evaluation. British Journal of Clinical Psychology, 30, 161-168.

5.6. BADDELEY, A.D. & WILSON, B.A. (1993). A developmental deficit in short-term phonological memory: Implications for language and reading. Memory, 1, 65-78.

5.7. BADDELEY, A.D. & WILSON, B.A. (1994). A case of word deafness with preserved span: Implications for the structure and function of short-term memory. Cortex, 29, 741-748.

5.8. BADDELEY, A.D. & WILSON, B.A. (1994). When implicit learning fails: Amnesia and the problem of error elimination. Neuropsychologia, 32, 53-68.

5.9. Cockburn, J., WILSON, B., BADDELEY, A. & Hiorns, R. (1990). Assessing everyday memory in patients with dysphasia. British Journal of Clinical Psychology, 29, 353-360.

5.10. Cockburn, J., WILSON, B.A., BADDELEY, A.D. & Hiorns, R. (1990). Assessing everyday memory in patients with perceptual deficits. Clinical Rehabilitation, 4, 129-135.

5.11. D'Erme, P., ROBERTSON, I., Bartolomeo, P. & Daniele, A. (1993). Unilateral neglect: The fate of the extinguished visual stimuli. Behavioural Neurology, 6, 143-150.

5.12. D'Erme, P., ROBERTSON, I.H., Bartolomeo, P., Daniele, A. & Gainotti, G. (1992). Early rightwards orienting of attention on simple reaction time performance in patients with left-sided neglect. Neuropsychologia, 30, 989-1000.

5.13. DE WALL, C., WILSON, B.A. & BADDELEY, A.D. (1994). The Extended Rivermead Behavioural Memory Test: A measure of everyday memory performance in normal adults. Memory, 2, 149-166.

5.14. EVANS, J. (1994). Physiotherapy as a clinical science: The role of single case research designs.

Physiotherapy Theory and Practice, 10, 65-68.
5.15. EVANS, J.J. & WILSON, B.A. (1992). A memory group for individuals with brain injury. Clinical Rehabilitation, 6, 75-81.
5.16. EVANS, J.J., WILSON, B.A., Wraight, E.P. & Hodges, J.R. (1993). Neuropsychological and SPECT findings during and after transient global amnesia: Evidence for the differential impairment of remote episodic memory. Journal of Neurology, Neurosurgery and Psychiatry, 56, 1227-1230.
5.17. Gray, J.M., ROBERTSON, I., Pentland, B. & Anderson, S. (1992). Microcomputer-based attentional retraining after brain damage: A randomised group controlled trial. Neuropsychological Rehabilitation, 2, 97-115.
5.18. Halligan, P., ROBERTSON, I.H., Pizzamiglio, L., Homberg, V., Weber, E. & Bergego, C. (1991). The laterality of visual neglect after right brain damage. Neuropsychological Rehabilitation, 1, 281-301.
5.19. Hartman, A., Pickering, R.M. & WILSON, B.A. (1992). Is there a central executive deficit after severe head injury? Clinical Rehabilitation, 6, 133-140.
5.20. Horn, S., SHIEL, A., McLellan, L., Campbell, M., Watson, M. & WILSON, B. (1993). A review of behavioural assessment scales for monitoring recovery in and after coma with pilot data on a new scale of visual awareness. Neuropsychological Rehabilitation, 3, 121-137.
5.21. Horn, S., Watson, M., WILSON, B.A. & McLellan, D.L. (1992). The development of new techniques in the assessment and monitoring of recovery from severe head injury: A preliminary report and case study. Brain Injury, 6, 321-325.
5.22. Kapur, N., Barker, S., Burrows, E. et al., WILSON, B.A. & Loates, M. (in press). Herpes Simplex Encephalitis: Long-term MRI and neuropsychological profile. Journal of Neurology, Neurosurgery and Psychiatry.
5.23. McDowell, I., Anderson, S., Wilson, C., Pentland, B. & ROBERTSON, I. (in press). Late rehabilitation for closed head injury: Clinical psychologists' interventions. Clinical Rehabilitation.
5.24. PATTERSON, K. & WILSON, B. (1990). A ROSE is a ROSE or a NOSE: A deficit in initial letter identification. Cognitive Neuropsychology, 7, (5/6), 447-477.
5.25. Pizzamiglio, L., Bergego, C., Halligan, P., Homberg, V., ROBERTSON, I., Weber, E., WILSON, B., Zoccolotti, P. & Deloche, G. (1992). Factors affecting the clinical measurement of visuo-spatial neglect. Behavioural Neurology, 5, 233-240.
5.26. Riccio, M., Pugh, K., Jadresic, D., Burgess, A., Thompson, C., WILSON, B., Lovett, E., Baldeweg, T., Hawkins, D.A. & Catalan, J. (1993). Neuropsychiatric aspects of HIV-1 infection in gay men: Controlled investigation of psychiatric, neuropsychological and neurological status. Journal of Psychosomatic Research, 37, 819-830.
5.27. Riccio, M., Thompson, C., WILSON, B.A., Morgan, D.J.R. & Lant, A.F. (1992). Neuropsychological and psychiatric abnormalities in myalgic encephalomyelitis: A preliminary report. British Journal of Clinical Psychology, 31, 111-120.
5.28. ROBERTSON, I.H. (1991). Use of left vs right hand in responding to lateralized stimuli in unilateral neglect. Neuropsychologia, 29, 1129-1135.

5.29. ROBERTSON, I.H. (1993). Cognitive rehabilitation in neurologic disease. Current Opinion in Neurology, 6, 756-760.

5.30. ROBERTSON, I.H. (1994). Methodology in Neuropsychological Rehabilitation research. Neuropsychological Rehabilitation, 4, 1-6.

5.31. ROBERTSON, I.H. (1994). Randomised controlled trials and single-instance experiments. Physiotherapy, 80, p. 339.

5.32. ROBERTSON, I.H. (in press). Persisting unilateral neglect: Compensatory processes within multiple interacting circuits. Neuropsychological Rehabilitation.

5.33. ROBERTSON, I.H. & Cashman, L. (1991). Auditory feedback for walking difficulties in a case of unilateral neglect: A pilot study. Neuropsychological Rehabilitation, 1, 175-183.

5.34. ROBERTSON, I.H. & Frasca, R. (1992). Attentional load and visual neglect. International Journal of Neuroscience, 62, 45-56.

5.35. ROBERTSON, I.H., Halligan, P.W., Bergego, C., Homberg, V., Pizzamiglio, L., Weber, E. & WILSON, B.A. (1994). Right neglect following right brain damage. Cortex, 30, 199-214.

5.36. ROBERTSON, I.H. & North, N. (1992). Spatio-motor cueing in unilateral left neglect: The role of hemispace, hand and motor activation. Neuropsychologia, 30, 553-563.

5.37. ROBERTSON, I.H. & North, N. (1993). Active and passive activation of left limbs: Influence on visual and sensory neglect. Neuropsychologia, 31, 293-300.

5.38. ROBERTSON, I.H. & North, N. (1993). Fatigue versus disengagement in unilateral neglect. Journal of Neurology, Neurosurgery and Psychiatry, 56, 717-719.

5.39. ROBERTSON, I.H. & North, N. (1994). One hand is better than two: Motor extinction of left hand advantage in unilateral neglect. Neuropsychologia, 32, 1-11.

5.40. ROBERTSON, I.H., North, N. & Geggie, C. (1992). Spatiomotor cueing in unilateral left neglect: Three case studies of its therapeutic effects. Journal of Neurology, Neurosurgery and Psychiatry, 55, 799-805.

5.41. ROBERTSON, I.H., Tegnèr, R., Goodrich, S. & Wilson, C. (in press). Walking trajectory and hand movements in unilateral left neglect: A vestibular hypothesis. Neuropsychologia.

5.42. SHIEL, A. & WILSON, B.A. (1992). Performance of stroke patients on the Middlesex Elderly Assessment of Mental State. Clinical Rehabilitation, 6, 283-289.

5.43. SHIEL, A., WILSON, B., Horn, S., Watson, M. & McLellan, L. (1993). Can patients in coma following traumatic head injury learn simple tasks? Neuropsychological Rehabilitation, 3, 161-175.

5.44. WILSON, B.A. (1991). Long term prognosis of patients with severe memory disorders. Neuropsychological Rehabilitation, 1, 117-134.

5.45. WILSON, B.A. (1991). Theory, assessment, and treatment in Neuropsychological Rehabilitation. Neuropsychology, 5, 281-291.

5.46. WILSON, B.A. (1992). Recovery and compensatory strategies in head injured memory impaired people several years after insult. Journal of Neurology, Neurosurgery, and Psychiatry, 55, 177-180.

5.47. WILSON, B.A. (1993). Ecological validity of neuropsychological assessment: Do neuropsychological indexes predict performance in everyday activities? Applied and Preventive Psychology, 2, 209-216.

5.48. WILSON, B.A. (1993). Editorial: How do we know that rehabilitation works? Neuropsychological Rehabilitation, 3, 1-4.
5.49. WILSON, B.A. (1994). Syndromes of acquired dyslexia: A 6- to 10-year follow-up study of seven brain-injured people. Journal of Clinical and Experimental Neuropsychology, 16, 354-371.
5.50. WILSON, B.A. & BADDELEY, A.D. (1993). Spontaneous recovery of impaired memory span: Does comprehension recover? Cortex, 29, 153-159.
5.51. WILSON, B.A., BADDELEY, A.D., EVANS, J. & SHIEL, A. (in press). Errorless learning in the rehabilitation of memory impaired people. Neuropsychological Rehabilitation.
5.52. WILSON, B.A., BADDELEY, A.D., SHIEL, A. & Patton, G. (1992). How does post-traumatic amnesia differ from the amnesic syndrome and from chronic memory impairment? Neuropsychological Rehabilitation, 2, 231-243.
5.53. WILSON, B.A. & Davidoff, J. (1993). Partial recovery from visual object agnosia: A 10 year follow-up study. Cortex, 29, 529-542.
5.54. WILSON, B.A. & IVANI-CHALIAN, R. (in press). Performance of Downs Syndrome adults on the children's version of the Rivermead Behavioural Memory Test. British Journal of Clinical Psychology.
5.55. WILSON, B.A., IVANI-CHALIAN, R., Besag, F.M.C. & Bryant, T. (1993). Adapting the Rivermead Behavioural Memory Test for use with children aged 5-10 years. Journal of Clinical and Experimental Neuropsychology, 15, 474-486.
5.56. WILSON, B.A. & PATTERSON, K. (1990). Rehabilitation for cognitive impairment: Does cognitive psychology apply? Applied Cognitive Psychology, 4, 247-260.
5.57. Wilson, C. & ROBERTSON, I.H. (1992). A home-based intervention for attentional slips during reading following head injury: A single case study. Neuropsychological Rehabilitation, 2, 193-205.
5.58. YOUNG, A.W., ROBERTSON, I.H., Hellawell, D.J., de Pauw, K.W. and Pentland, B. (1992). Cotard delusion after head injury. Psychological Medicine, 22, 799-804.
Submitted
5.59. ROBERTSON, I.H., Tegnèr, R., Tham, K., Lo, A. & NIMMO-SMITH, I. Sustained attention training for unilateral neglect: theoretical and rehabilitation implications. (Manuscript submitted to Journal of Clinical and Experimental Neuropsychology).
5.60. WILSON, B.A. Semantic memory impairments following non-progressive brain damage. (Manuscript submitted to Memory)
Invited Chapters and Commentaries
5.61. D'Erme, P., Gainotti, G., Bartolomeo, P. & ROBERTSON, I. (1994). Early ipsilateral orienting of attention in patients with contralateral neglect. In M.J. Riddoch & G.W. Humphreys (Eds.), Cognitive Neuropsychology and Cognitive Rehabilitation (pp. 205-223). Hove: Lawrence Erlbaum Associates.
5.62. Halligan, P., ROBERTSON, I., Pizzamiglio, L., Hömberg, V., Weber, E. & Bergego, C. (1993). The assessment and classification of visual inattention after right hemisphere damage. In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European

Concerted Action (pp. 73-78). Tübingen: Gunter Narr Verlag.
5.63. Marshall, J.C., Halligan, P.W. & ROBERTSON, I.H. (1993). Contemporary theories of unilateral neglect: A critical review. In I.H. Robertson & J.C. Marshall (Eds.), Unilateral Neglect: Clinical and Experimental Studies (pp. 311-329). Hove, Sussex: Lawrence Erlbaum Associates.
5.64. Pizzamiglio, L., Bergego, C., Halligan, P., Hömberg, V., ROBERTSON, I., Weber, E., WILSON, B., Zoccolotti, P. & Deloche, G. (1993). Factors affecting the clinical measurement of visuo-spatial neglect. In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European Concerted Action (pp. 59-72). Tübingen: Gunter Narr Verlag.
5.65. ROBERTSON, I.H. (1993). The rehabilitation of visuo-spatial, visuo-perceptual and apraxic disorders. In R.J. Greenwood, M.P. Barnes, T.M. McMillan & C.D. Ward (Eds.), Neurological Rehabilitation (pp. 179-188). Edinburgh: Churchill Livingston.
5.66. ROBERTSON, I.H. (1993). The relationship between lateralised and non-lateralised attentional deficits in unilateral neglect. In I.H. Robertson & J.C. Marshall (Eds.), Unilateral Neglect: Clinical and Experimental Studies (pp. 257-275). Hove, Sussex: Lawrence Erlbaum Associates.
5.67. ROBERTSON, I.H. (1994). The rehabilitation of attentional and hemi-inattentional disorders. In M.J. Riddock & G.W. Humphreys (Eds.), Cognitive Neuropsychology and Cognitive Rehabilitation (pp. 173-186). Hove: Lawrence Erlbaum Associates.
5.68. ROBERTSON, I.H. (in press). Neuropsychology: Recovery after brain lesions. In M. Swash & Wilden (Eds.), Outcome of Neurological and Neurosurgical Disorders. Cambridge: Cambridge University Press.
5.69. ROBERTSON, I., Bergego, C., Halligan, P., Hömberg, V., Pizzamiglio, L., Weber, E. & WILSON, B. (1993). Why do people with unilateral left neglect sometimes neglect to the right? In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European Concerted Action (pp. 79-84). Tübingen: Gunter Narr Verlag.

5.70. ROBERTSON, I. & Halligan, P. (1993). Introduction to unilateral neglect. In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the Assessment and Rehabilitation of Brain-damaged Patients: Perspectives from a European Concerted Action (pp. 55-57). Tübingen: Gunter Narr Verlag.
5.71. ROBERTSON, I.H., Halligan, P.W. & Marshall, J.C. (1993). Prospects for the rehabilitation of unilateral neglect. In I.H. Robertson & J.C. Marshall (Eds.), Unilateral Neglect: Clinical and Experimental Studies (pp. 279-292). Hove, Sussex: Lawrence Erlbaum Associates.
5.72. Skilbeck, C. & ROBERTSON, I.H. (1992). Computer-assistance in the management of memory and cognitive impairment. In B.A. Wilson & N. Moffat (Eds.), Clinical Management of Memory Problems (Second edition) (pp. 155-188). London: Chapman & Hall.
5.73. WILSON, B.A. (1992). Memory therapy in practice. In B.A. Wilson & N. Moffat (Eds.), Clinical Management of Memory Problems (2nd edition) (pp. 120-153). London: Chapman & Hall.

5.74. WILSON, B.A. (1992). Rehabilitation and memory disorders. In L.R. Squire & N. Butters (Eds.), Neuropsychology of Memory (Second edition) (pp. 315-321). New York: The Guilford Press.
5.75. WILSON, B.A. (1992). Single-case experimental designs in Neuropsychological Rehabilitation. In B.P. Rourke, L. Costa, D. Cicchetti, K.M. Adams & K.J. Plasterk (Eds.), Methodological and Biostatistical Foundations of Clinical Neuropsychology (pp. 112-130). Lisse, Amsterdam: Swets & Zeitlinger. [Reprinted from 1987]
5.76. WILSON, B.A. (1993). Coping with memory impairment. In G.M. Davies & R.H. Logie (Eds.), Memory in Everyday Life (pp. 461-481). Amsterdam: Elsevier Science Publishers, B.V.
5.77. WILSON, B.A. (1993). Recent developments in the assessment of memory. In F.J. Stachowiak, R. De Bleser, G. Deloche, R. Kaschel, H. Kremin, P. North, L. Pizzamiglio, I. Robertson, & B. Wilson, (Eds.), Developments in the Assessment and Rehabilitation of Brain-Damaged Patients: Perspectives from a European Concerted Action (pp. 99-105). Tübingen: Gunter Narr Verlag.
5.78. WILSON, B.A. (in press). La riabilitazione dei disturbi della memoria. In A. Mazzucci (Ed.), La Riabilitazione Neuropsicologia (Second edition). Bologna: Societa editrice il Mulino.
5.79. WILSON, B.A. (in press). Management and remediation of memory problems in brain damaged adults. In A.D. Baddeley, B.A. Wilson & F. Watts (Eds.), Handbook of Memory Disorders. Chichester: John Wiley & Sons.
5.80. WILSON, B.A. (in press). Memory rehabilitation: Compensation for memory problems. In L. Bäckman & R. Dixon (Eds.), Psychological Compensation. Hillsdale, N.J.: Lawrence Erlbaum Associates.
5.81. WILSON, B.A. (in press). The ecological validity of neuropsychological assessment of traumatically brain injured patients. In R.J. Sbordone (Ed.), The Ecological Validity of Neuropsychological Testing. Paul M Deutsch Press.
5.82. WILSON, B.A. & Moffat, N. (1992). The development of group memory therapy. In B.A. Wilson & N. Moffat (Eds.), Clinical Management of Memory Problems (2nd edition) (pp. 242-273). London: Chapman & Hall.
5.83. WILSON, B.A. & Wearing, D. (in press). Prisoner of consciousness: A permanent state of just awakening. In R. Campbell & M. Conway (Eds.), Broken Memories: Neuropsychological Case Studies. Oxford: Blackwell.
5.84. WILSON, B.A., SHIEL, A., Watson, M., Horn, S. & McLellan, D.L. (in press). Monitoring behaviour during coma and post-traumatic amnesia. In B. Uzzell & A-L. Christensen (Eds.), Progress in the Rehabilitation of Brain-Injured People. Boston: Kluwer Academic Publishers.

Tests and Patents

5.85. Kopelman, M., WILSON, B. & BADDELEY, A.D. (1990). The Autobiographical Memory Interview. Thames Valley Test Company.
5.86. ROBERTSON, I.H., WARD, T. & RIDGEWAY, V. (in press). The Test of Everyday Attention. Flempton: Thames Valley Test Company.
5.87. WILSON, B.A., IVANI-CHALIAN, R. & Aldrich, F. (1991). The Rivermead Behavioural Memory Test for Children aged 5-10 years. Bury St Edmunds: Thames Valley Test Company.

Dissemination

5.88. Halligan, P. & ROBERTSON, I.H. (1992). The assessment of unilateral neglect. In J. Crawford, W. McKinlay & D. Parker (Eds.), Principles and Practice of Neuropsychological Assessment (pp. 151-175). Lawrence Erlbaum Associates.

5.89. Powell, G.E. & WILSON, B.A. (in press). Investigation of neurological problems. In S.J.E. Lindsay & G.E. Powell (Eds.), A Handbook of Clinical Adult Psychology, Second edition. Aldershot: Gower Press.
5.90. Vincent, C. & ROBERTSON, I.H. (1993). Recovering from a medical accident: The consequences for patients and their families. In C. Vincent, M. Ennis & R. Audley (Eds.), Medical Accidents (pp. 150-166). Oxford: Oxford University Press.
5.91. WILSON, B.A. (1992). Assessment and management of memory problems. In N. von Steinbüchel, D.Y. von Cramon & E. Pöppel (Eds.), Neuropsychological Rehabilitation (pp. 195-202). Berlin: Springer-Verlag.
5.92. WILSON, B.A. (in press). Cognitive Problems Following a Stroke. London: Chest, Heart and Stroke Association.
5.93. WILSON, B.A. (in press). Neuropsychological Rehabilitation. In J.G. Beaumont & J. Sergeant (Eds.), The Blackwell Dictionary of Neuropsychology. Oxford: Blackwell.
5.94. WILSON, B.A. (in press). Research and evaluation in rehabilitation. In D.L. McLellan & B.A. Wilson (Eds), The Handbook of Rehabilitation Studies. Cambridge: Cambridge University Press.
5.95. WILSON, B.A. (in press). The management of acquired cognitive disorders. In D.L. McLellan & B.A. Wilson (Eds.), The Handbook of Rehabilitation Studies. Cambridge: Cambridge University Press.
5.96. WILSON, B.A. & Powell, G.E. (in press). Neurological problems: Treatment and rehabilitation. In S. Lindsay & G.E. Powell (Eds.), A Handbook of Clinical Adult Psychology (Second edition). Aldershot: Gower Press.
5.97. WILSON, B.A. & ROBERTSON, I.H. (1992). Editorial. Neuropsychological Rehabilitation, 2, 1-2.
5.98. WILSON, B.A. & Staples, D. (1992). Working with people with physical handicap. In J. Marzillier & J. Hall (Eds.), What is Clinical Psychology? (2nd edition) (pp. 142-198). Oxford: Oxford University Press.

REFERENCES TO OTHER WORK

BADDELEY, A.D. & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), The Psychology of Learning and Motivation, vol. 8 (pp. 47-89). New York: Academic Press.
Levin, H.S., Grossman, R.G., Rose, J.E. & Teasdale, G. Long term neuropsychological outcome of closed head injury. Journal of Neurosurgery, 50, 412-422, 1979.
SHALLICE, T. (1982). Specific impairments of planning. Philosophical Transactions of the Royal Society London B, 298, 199-209.
Shores, E.A., Marosszeky, J.E., Sandanam, J. & Batchelor, J. (1986). Preliminary validation of a clinical scale for measuring the duration of post-traumatic amnesia. The Medical Journal of Australia, 144, 596-572.
Snowden, J., Griffiths, H. & Neary, D. (in press). Semantic dementia: Autobiographical contribution to preservation of meaning. Cognitive Neuropsychology.
WILSON, B.A., Cockburn, J. & BADDELEY, A.D. (1985). The Rivermead Behavioural Memory Test. Bury St Edmunds: Thames Valley Test Company.

Grant: From the Medical Research Council (joint holder): £104,000 (Grant No. SPG 8175555) for development of assessment procedures for use with patients surviving severe head injury. (B.A. Wilson, D.L. McLellan & M.J. Campbell) (3 years)

Collaborations

Robertson

UK based

McMillan - Wolfson Rehabilitation Center, London

Wilson - Astley Ainslie Hospital, Edinburgh

Hodges - Neurology, Cambridge

O'Connel - Stroke Research Unit, Gateshead

Halligan - Neurology, Oxford

Marshall - Neurology, Oxford

Lo - Rehabilitation, Southampton

North - Psychology, Odstock Hospital, Salisbury

Outside UK

Tegnèr - Neurology, Karolinska Institute, Stockholm

Pizzamiglio - Psychology, Rome

Nico - Psychology, Rome

Gainotti - Neurology, Rome

D'Erme - Neurology, Rome

Wilson

UK based

Alderman - Clinical Psychology, St. Andrews Hospital, Northampton

Burgess - Psychology, University College London

Carr - Psychology, St. George's Hospital, London

Cockburn - Rivermead Rehabilitation Centre, Oxford

Della Sala - Psychology, Aberdeen

Green - Psychiatry, St. Thomas's Hospital, London

Hodges - Neurology, Cambridge

Huppert - Psychiatry - Cambridge

Kapur - Wessex Neurological Centre, Southampton

Kopelman - Psychiatry, St. Thomas's Hospital, London

McKenna - Psychiatry, Cambridge

McLellan, Shiel, Ward - Rehabilitation, Southampton

Pickard - Neurosurgery, Cambridge

Outside UK

Chiapello, Kime, Prigatano - Barron Neurological Institute, Phoenix

Hersh, Treadgold - Interactive Proactive Mnemonic Systems, San Jose

COGNITION AND EMOTION

Barnard 0.75, Levey 1.0, MacLeod 1.84, Mathews 2.60, Nimmo-Smith 0.75, Teasdale 5.0, Watts 4.25, Williams 1.67, A Young 0.43, Dritschel (SO) 0.75, Hutton (SO) 1.08, Lloyd (SO) 0.6, Milroy (HSO) 2.0, Scott (SO) 0.15, Taylor (HSO) 1.75

Total Person Years: Scientists 18.3; Research Support 5.9

Abstract

Objectives

Work in this programme aims to investigate the cognitive processes that are involved in the elicitation, maintenance, and control of normal and abnormal emotional states. This knowledge is applied to the development and evaluation of psychological treatments for emotion-related disorders. With regard to anxiety and worry, the goal is to characterise the processing of emotionally-threatening information, differences between anxious and non-anxious individuals, the role of threat-related biases in maintaining anxious mood, and the extent to which these processes are automatic and invariable, or are modifiable in nature. Work in depression aims to develop and evaluate information-processing accounts of the nature of mood-dependent negative thinking and its role in the onset and maintenance of depression, and to study ways in which negative thinking and affect can be brought under attentional control. The resulting knowledge is applied to understand how psychological treatments prevent depressive relapse and to develop and evaluate improved treatments. The objective of research on the recognition of emotion is to fractionate components of the perception of emotional expression, to determine the relation between processing of facial emotional expression and both vocal expression and personal identity, and to investigate cognitive and emotional components of delusions, especially delusional misidentification.

Scientific progress and achievements over the past five years

Work in anxiety and worry has suggested that these states are associated with increased attention to threatening information in the environment; for example, threatening distractors may capture attention in anxious subjects, even when the emotional stimuli are presented outside awareness. In non-clinically anxious subjects, interfering effects of threatening material were modified by experimental manipulations, and in anxious patients, interference was no longer apparent after recovery; these results suggest a degree of plasticity of threat-related biases, of obvious therapeutic relevance. Although given greater attentional priority, threatening words were not found to be especially well recalled by anxious subjects, suggesting that the subjects may inhibit elaborative processing of threat-related material. Relatedly, heightened subjective risk for negative events in anxious subjects was found to be associated with difficulties in generating reasons why such events would not happen. The overall pattern of anxiety-related biases observed could act to maintain anxious mood and increase vulnerability to emotional disorder.

Comparisons of worriers and insomniacs have shown clear dissociations between concerns about sleep and other concern-related cognition. A novel cognitive treatment of insomnia has been piloted.

A comprehensive information-processing account of cognitive-affective interaction in depression has been developed that resolves difficulties in the existing experimental and clinical literature. Counterintuitive

predictions from this account have been confirmed, suggesting that depressive cognitive biases result from shifts in generic schematic mental models, rather than changes in accessibility of individual constructs. Methods to assess affect-related schematic mental models have been developed and evaluated. Production of stimulus-independent thought has been shown to depend on central executive resources of working memory. Overgeneral memory deficit in depression has been shown to be associated with poor problem-solving, difficulty in generating images of prospective events, and poor clinical prognosis. A collaborative clinical trial of cognitive therapy for residual depressive chronicity has been mounted, including new measures of cognitive mediating variables. A new form of attentional control treatment to prevent depressive relapse has been developed and shown to be acceptable and applicable.

Neuropsychological investigations on the recognition of emotion have demonstrated that processing of facial expression and processing of identity from the face are independent.

Future plans for the next five years

Studies in high-anxious normal and patient subjects will investigate the following specific components of a model of cognitive bias in anxiety/worry: (i) early non-conscious detection of threat (ii) implicit perceptual encoding of threatening stimuli (iii) intentional inhibition of elaborative encoding (iv) the extent to which instructional control is possible, and (v) the role of schematic learning.

Studies in depressed patients and (high neuroticism) individuals vulnerable to depression will investigate aspects of the theoretical model of affect maintenance/regulation developed in the current grant period: (i) the nature of depression-related schematic models and their influence on thinking (ii) the role of central executive resources in the maintenance of affect and in affective re-appraisal (iii) the voluntary redeployment of central attentional resources in the regulation of affect (iv) the cognitive mediation of any prophylactic effects of cognitive therapy observed in the collaborative clinical trial (v) the development of more cost-effective methods to prevent relapse following treatment for the presenting episode of depression.

Investigations on the recognition of emotion will clarify whether facial expression processing is implemented by neural mechanisms which are face-specific or supramodal, and whether these are emotion-specific or used in all forms of social interaction. Neuropsychological case studies of impairments in expression processing after bilateral amygdalotomy and frontal lobe lesions will be combined with studies of priming and related effects on the recognition of facial expressions by normal people. Deficits predicted from theoretical models of delusional misidentification will be investigated.

Implications for improving health, health care and wealth creation

Mental Illness is a Health of the Nation Priority Area, and Prevention of Relapse and Recurrence in Depression is a Health Department R and D Priority Area. Work on anxiety and depression provides a basis for developing objective methods to assess risk of developing emotional disorders and for improving interventions to reduce risk of onset and relapse. In depression, the effectiveness and mechanisms of action of an existing method of treatment (cognitive therapy) are being investigated, and a novel preventive intervention is being developed. Work on face and emotion recognition should lead to improved understanding of social disabilities due to brain injury, dementing and psychiatric illnesses. Increasing the effectiveness and efficiency of treatments for emotional disorders also has potential for considerable wealth savings as the social and familial costs of these frequent disorders are considerable: in a study by Wells et al. (1989), measures of functioning showed significantly greater disability in depression than in six out of eight major chronic medical conditions with which it was compared

NATURE OF COGNITIVE BIAS AND COGNITIVE CONTENT IN WORRY AND ANXIETY *(Dalgleish, Mathews, Watts, Williams)*

Introduction

The purpose of this project is to characterise the manner in which emotionally threatening information is processed, and how these processes differ between anxious and non-anxious individuals. It builds on previous work in which it has been demonstrated that anxious individuals (clinical patients and, to a lesser extent, normal subjects who are often anxious) differ in several important respects from non-anxious controls. These differences include: elevated estimations of the risk of future negative events; selective attention to threatening stimuli; greater interference on task performance from threatening distractors that are incidentally present; and selection of the more threatening interpretation of ambiguous events (Williams et al., 1988). The evidence for equivalent effects in memory, however, is mixed and contradictory: anxious patients do recall more such personally threatening events in tests of autobiographical memory, but do not consistently recall more threatening stimuli in experiments when extent of exposure is controlled. On the basis of these results, Mathews & MacLeod (6.66) have proposed that anxiety-related biases in the processing of emotional information are such as to increase the intake of information from the environment that is related to possible danger, although not always in a form that can be consciously recalled. Furthermore, it is possible that this encoding bias could play a role in maintaining anxious mood and/or increasing vulnerability to emotional disorder under stressful conditions.

A Nature of Interference Effects due to Threatening Distractors*(Mathews)*

Robust interference effects have been found in the speed of colour-naming emotional words, such that anxious patients are slowed by the presence of words related to the content of their worries and concerns. There are several possible mechanisms that could account for this effect, including an automatic (pre-attentive) decision mechanism that allocates processing priority to some emotional words, or a conscious (post-attentional) process in which subjects voluntarily focus on the words or their implications.

A1. Paradoxical Suppression of Interference by Fear Arousal: The presence of a controllable component in the emotional interference effect is suggested by three experiments on normal subjects with fears of non-poisonous snakes. Attempting to replicate the slowing due to phobic words documented earlier (Watts, McKenna, Sharrock & Trezise, 1986), Mathews and Sebastian (6.30) unexpectedly failed to find any interference in mildly phobic subjects when tested in the presence of a harmless snake. Interference was re-established in a second experiment without a snake present, with phobic but not control subjects being slower to name the ink colour of snake-related words. Finally, in a third experiment, induction of fear by another means (the presence of a large but harmless tarantula) also abolished interference due to snake-related words.

It was concluded that under conditions of fear arousal, non-clinical subjects may be able to prevent the allocation of processing priority to the relevant words.

A2. Interference Without Awareness in Anxious Patients: In other experiments (6.65) interference due to threatening words in anxious patients persisted even under conditions that prevented subjects being aware of the nature of the relevant words. In a further study, words were presented either for 16ms and followed by a mask that prevented subjects from being able to read them, or the words remained visible until the background colour was named. In both cases, anxious patients were slowed by the presence of threatening words, but depressed patients and controls were not (6.31). Since the extent of interference was not affected by exposure condition, it would appear that the processes causing interference are not under direct conscious control. Two conclusions are possible: either subjects can control interference provided that they are aware of the words, or such post-awareness control is possible for normal subjects but not for anxious patients. The latter seems more likely, because patients do not seem able to prevent interference, despite high levels of current anxiety. The emerging hypothesis, therefore, is that high-anxious normals can effortfully counter-act the effect of interfering emotional stimuli of which they are aware, but that this control is reduced or lost with the onset of an anxiety disorder.

B. Memory for Threatening Events and Reactions *(Watts, Dalgleish, Coyle)*

Other results suggest that effortful control processes might help to explain the mixed findings of mood-congruent memory experiments in anxious subjects. Normal subjects reporting fear of harmless spiders, shown words that were either neutral or related to spiders, later recalled fewer fear-related than neutral words. In a second experiment, fearful subjects recalled fewer spider-related words than did controls, but only when tested in the presence of a live spider (6.47). Despite their poor recall, these subjects had a number of intrusion errors related to spiders, suggesting that they had encoded the words in terms of general emotional category, rather than the exact form that was presented. In two further experiments, this bias against threatening words proved difficult to replicate, and there were no consistent differences between groups either for spider-related or for fear-response words (6.44, 6.45). Overall, consistent with previous findings, these results confirm that anxious subjects do not usually show enhanced recall of fear-related words, perhaps because they encode by generic emotional meaning, and avoid processing other details.

C. Effects of Treatment on Cognitive Bias*(Mathews)*

The hypothesis advanced earlier, to the effect that interference from threatening cues can be inhibited by high-trait anxious normals but not by currently anxious patients, suggests that control over interference effects may return following successful treatment. The alternative view, that interference is independent of current state, would predict that effects would persist beyond apparent recovery. To examine this issue, patients were assessed before and after anxiety management training, using measures that had previously been found to distinguish them from normal controls. Before treatment, anxious patients (but not controls) were significantly slowed by threatening distractors, both in colour-naming and during attentional search for a neutral target. After treatment, and at follow-up, no significant interference effects remained, and there were no differences in this respect between recovered anxious and control subjects (6.29). This outcome is taken as provisional support for the view that attentional interference from threat distractors is not invariably present in anxiety-prone subjects, but depends on current state factors (e.g. mood or stress) that elicit a vigilant processing style in vulnerable individuals. This hypothesis predicts that stressful events would re-instate interference and other vigilance effects in recovered patients, but not in low anxiety-prone subjects.

D. Cognitive Characteristics of Worry

Self-report of excessive worry is the main symptom required for a DSM III diagnosis of generalised anxiety disorder, as well as being an important component of many other emotional disorders. Subjects recruited from advertisements for "worriers" typically report levels of anxiety in the low clinical range, and many have sought help for anxiety symptoms in the past. The nature of excessive worry therefore seems worthy of further study, both in its own right, and to establish whether these worry-prone subjects show the same processing style that has been found in anxious patients.

D1. Worry and Subjective Risk (MacLeod, Williams, Bekerian, Mathews): Anxious and depressed patients estimate the risk of hypothetical negative events happening to them in the future as significantly higher than do normal controls. This inflation of risk was investigated by requiring subjects, who were either high- or low-frequency worriers, to think about possible future events, and to list reasons why these events might or might not happen to them. Consistent with expectations, worriers always revealed higher subjective probabilities for negative events, and the most anxious among them also had greater difficulty in generating reasons why such events would not happen to them. When they did generate such reasons, however, this reduced their subjective risk estimates, although these remained higher than for non-worriers, whose estimates were unchanged (6.23).

In another study, subjects imagined a series of positive or negative events and generated reasons why they might happen. This manipulation induced mildly positive or negative mood state, depending on valence of the events, together with an elevation in subjective risk for all other events of the same valence. Two further experiments demonstrated that this elevation in subjective risk was made up of two components: a global effect on the perceived risk for all mood-congruent events, and a specific priming effect associated with greater elevations in the risk of events that subjects had thought about (6.8). In general, these results support the hypothesis that worry about a topic increases the subjective risk that the feared event will actually occur, and may thus serve further to increase anxiety.

D2. Worry and Speed of Access to Negative Meaning (Mathews, Milroy): The above results, and related findings obtained with anxious patients, suggested that frequent worriers should be highly practiced in perceiving the negative meaning of events. This was tested in three experiments in which subjects made a variety of speeded affective judgements about threatening or non-threatening words. Contrary to prediction, no significant differences were found between high- and low-frequency worriers. Frequency of worry is thus not associated with accessibility of negative meaning, at least in the case of simple verbal stimuli, but may depend on other automatic processes that are unrelated to these conscious judgements (6.28).

D3. Effect of Instructions on Worry (Mathews, Milroy): Instructions not to think about a topic have been claimed to result in a later paradoxical rebound in the unwanted thought. Since this suggests that treatments based on suppressing worry might be counter-productive, instructions not to worry about a specified topic for five minutes were compared to two control conditions: one in which high- and low-worry subjects were told to worry about a specified topic for the same time, and one in which they were asked to think about another interesting and pleasant topic. In the 20 minutes following, when no special instructions were in effect, subjects were periodically interrupted for a report on mental content. The main result was that the high-worry subjects always reported more negative content, regardless of condition, but the suppression condition was followed by slightly increased frequencies of pleasant thoughts (6.27). It is concluded that treatments involving suppression of worry are more likely to be helpful than harmful.

Conclusions

The studies summarised above suggest the following conclusions: (a) Emotional interference effects can persist even when threatening stimuli are presented outside awareness. With awareness, interference may be inhibited under some conditions in non-clinical fearful subjects, but probably not in anxious patients. (b) Despite causing interference, threatening words are not better recalled by anxious subjects, perhaps due either to generic emotional encoding, or avoidance of elaboration. (c) After people recover from an anxiety state, interference from threatening stimuli is no longer apparent. Further research is needed to determine the limits of this change. (d) Preliminary investigations show that subjects describing themselves as "worriers" are similar to anxious patients in having increased subjective risk of negative events, but despite this, do not have faster conscious access to negative meanings. Suppression of worry, and generation of reasons why negative events might not happen, could be explored for therapeutic potential in future research.

FUTURE PROPOSALS

Introduction: Selective Encoding of Emotional Information in Worry and Anxiety States

Earlier research has shown that individuals prone to anxiety (whether within clinical or high-trait anxious normal populations) selectively process information relating to threat or danger, in comparison with non-anxious controls. Anxious subjects attend to threatening words in preference to other competing information, and select the more threatening interpretation of ambiguous events (6.66). These selective processes occur even when the relevant stimuli are presented under conditions that prevent subjects being fully aware of them, implying that at least some of the processes involved are automatic and non-conscious in nature. In contrast, anxious subjects are not necessarily better at remembering threatening stimuli in "explicit" tests of memory, although there are some indications that they are primed more strongly in "implicit" tests, when subjects are not attempting to recall but performance will be facilitated by prior exposure. The implication is that anxiety-prone subjects are biased towards processing information in a manner that will enhance the impression of being in danger, without necessarily being able to recall or even be aware of the cues that evoke this impression. Thus, even if an anxiety state has its origins elsewhere, the associated pattern of selective processing will tend to enhance vigilance and anxious expectation (worry), and in this way serve to maintain anxious mood.

The emerging hypothesis is that anxiety is characterised by a "vigilant" operating mode of the cognitive system, in which processes involved in the detection of threat are facilitated, and others are inhibited. In vigilant mode, threatening components or aspects of events are automatically selected at an early (pre-attentive and non-conscious) stage, and are subsequently given priority for attentional resources in preference to competing stimuli. In addition, perceptual properties of threatening events are selectively encoded, thus priming subsequent detection of the same event. However, because anxious subjects may try to reduce distress by inhibiting conscious processing (such as elaborative thought about the details of the threat), the event will not be well encoded in other ways. The hypothesis thus predicts that anxiety-prone individuals will encode events according to the following sequence: (i) an early automatic mechanism detects threatening aspects of a stimulus; (ii) these aspects are then given attentional priority over competing aspects; (iii) perceptual properties of the threatening stimulus are preferentially encoded; (iv) further semantic processing may then be inhibited with varying success; (v) the same process will then be re-enacted more fluently when related cues are encountered again, without requiring the subject's awareness or intent.

Non-anxious individuals do not selectively encode mildly threatening stimuli in the same way, and are either attentionally indifferent, or more attentive to positive stimuli. It is assumed, however, that if more intense stimuli signalling imminent danger are detected, then all subjects become vigilant. That is, normal subjects are assumed to react in an adaptive way, dependent on the current state of danger, while high anxiety-prone subjects remain chronically in a vigilant mode. A final part of this hypothesis is that the main coping strategy available to a high-trait anxious individual is the inhibition of conscious rehearsal, by using distraction from, or efforts to suppress, upsetting thoughts. Since such coping strategies are effortful (in that they call on limited cognitive resources), they will eventually fail if anxious mood and/or perceived threats become too severe. This eventual failure is postulated to correspond to the onset of clinical disorder. Progress in establishing or refuting these hypotheses is therefore likely to provide clues as to what methods should reduce excessive levels of anxiety or worry and the risk of developing emotional disorders.

Because previous research has already provided strong evidence for selective attentional and interpretive bias in anxiety-prone subjects, future work will focus on the remaining parts of the hypothesis. In each study the performance of anxious subjects will be contrasted with that of matched controls, on experimental tasks that require processing emotionally threatening and neutral information. Subject groups will be selected using questionnaires measuring trait-anxiety, negative emotionality, or frequency of worry, from among our existing panel (some of whom have been recruited using newspaper advertisements requesting volunteers who have problems with excessive anxiety and worry), or from among patients being treated elsewhere for anxiety disorders (we are currently investigating collaboration in this respect with the Department of Psychology at the Institute of Psychiatry, London).

A. Early Detection of Threatening Meaning *(Mathews, Milroy)*

It was predicted above that high-anxious subjects should be more sensitive to the threat value of stimuli than controls, even at the earliest (pre-attentive) stage of processing. This hypothesis derives from the finding that threatening words slow performance in anxious subjects even when the interfering stimuli are presented out of attention (6.66) or awareness (6.53). However, in three preliminary experiments (6.28) no differences were found between anxious and non-anxious groups in speed of making affective decisions for threatening words (e.g. cancer: good or bad?). This result appears paradoxical, as it is difficult to understand why anxious (but not control) subjects show differential interference reactions to threatening words, if there are no differences in their assessment of stimulus threat value. Several alternative explanations will be considered.

(1) It may be that anxious subjects are faster in detecting threat pre-attentively, but that this is not revealed by decisions that can be made using access to general knowledge about words, because the latter is equally available to all subjects.

(2) Alternatively, perhaps there are no differences in speed of pre-attentive detection of threat, but anxious subjects give higher priority to assessing threat value after initial pre-attentive detection, when in competition with other types of information.

(3) Finally, it could be that emotional encoding differences do not arise unless events are interpreted within a priming context that activates a relevant concern.

A1. Affective Decisions without Word Identification: If the use of general knowledge about words obscures possible differences, then effects could still emerge when subjects are forced to guess based on their "intuition", because direct knowledge of word identity cannot be used. Threatening words (e.g. cancer), non-threatening words (e.g. carpet), or non-word letter-strings will be presented briefly (e.g. 16-100ms), followed by an obscuring pattern mask. The information available at different exposure times can be assessed by immediately subsequent forced guessing tasks, for example: word present or absent?, valence (good or bad?), or (3) word form (cancer or tumour?). Hypothesis (1) would be supported if the performance of anxious subjects on the valence task differs from controls, for trials when other types of guesses remain at chance level. If not, we will proceed on the assumption that any differences in early detection of threat do not influence conscious report.

A2. Effects of Dividing Attention: Assuming that anxious subjects give priority to assessing threat value after pre-attentive detection, then differences would only be observed when subjects are simultaneously required to perform another task. This will be tested by briefly exposing subjects to threatening and non-threatening words under conditions of full or divided attention (e.g. by simultaneously presenting two digits that are to be summed in the divided attention condition), and then assessing the type of information that is extracted using tasks similar to those described above. Hypothesis (2) would be supported by finding that threat-related judgements are facilitated in anxious subjects relative to controls, but only in the divided attention condition.

A3. Contextual Priming Effects: A third alternative would be to suppose that affective decisions will only differ if a relevant personal concern has been primed by the context. Priming of this type could be accomplished in several ways: for example, subjects could first be asked to think about an area of personal concern, followed by a task, as in (A2) above, that involves threatening words related or unrelated to that concern. Alternatively, brief scenarios related to personal concerns may be constructed, ending in a word whose meaning is determined by the context in which it occurs. Subjects will thus make speeded affective decisions for the same word, but with emotional meaning determined by context. For example, the word "lump" should be judged as "bad" in the context of the sentence "You are looking at your face in the mirror when you notice a ....", but as "good" in the context of "You are looking for your lost wallet in the bedclothes when you notice a ....". Hypothesis (3) would be supported if decisions for threatening words are speeded for anxious subjects only in the context of an active concern.

B. Implicit Perceptual Encoding of Threatening Stimuli*(Mathews, Milroy)*

B1. Primed Word Completion: Evidence has been obtained previously that anxious subjects are primed more by prior exposure to threatening words, in a subsequent word-stem completion task. Because this has proved difficult to replicate, and word completion is sometimes thought to be contaminated with conscious recall processes, this tentative finding will be checked using methods that allow estimation of automatic priming effects, independent of conscious recollection. Two options are being piloted (by Ann Rafter): (i) instructing subjects either to include or to exclude previously seen words in each stem completion trial should allow separate estimates of conscious and unconscious influences (conscious influences are estimated by subtracting the proportion of hits obtained under "exclude" instructions from the proportion obtained under "include" instructions); (ii) requiring subjects to report whether each completed word had been seen previously or not. The hypothesis above predicts that only the estimate of unconscious influences will show evidence that anxious subjects encode more information about threatening stimuli.

B2. Primed Word Identification: The tachistoscopic identification task, in which subjects attempt to read words that are displayed very briefly and then masked, has been claimed to be less contaminated with conscious memory processes. Pilot work with this method has shown a significantly greater repetition priming effect for threatening stimuli in high-worry subjects, but this was associated with a less accurate baseline for new threatening words, making interpretation difficult. Studies of this effect will be continued, starting with an attempted replication, and going on to vary the task so as to check for response bias explanations (e.g., by including foils that resemble target words to allow signal detection analysis, or using forced choices between target and foils). The prediction is that, after taking account of any response bias effects, this task should reveal more accurate identification of previously exposed threatening words in anxious subjects, even in the absence of differences in tasks dependent on conceptual processing (such as better recall).

C. Failure to Encode Other Aspects of Meaning *(Dalgleish, Mathews, Milroy)*

This hypothesis arose from failures to find better recall or recognition for threatening words in anxious subjects, despite evidence of selective attention to the same stimuli. Such effects could occur if, after a threatening event had been emotionally and/or perceptually encoded, anxious subjects inhibit further elaborative processing, thus handicapping subsequent retrieval. If true, this generates a new prediction: that semantic links between memories for threatening events and other information in memory would be relatively poor. Within this framework, psychological therapy can be seen as the process of establishing new links in memory with other (less threatening) information.

C1. Intentional Forgetting: One method of studying intentional inhibition is via the "directed forgetting" paradigm, in which subjects instructed to forget some of the words after they have seen them are then less likely to be able to recall these items on later test. Pilot work by Dalgleish suggests that subjects are more able to "forget" threatening than neutral words in this way, and he will extend this work to include anxious patients. If these subjects are particularly able to "forget" threatening words, this would support an intentional inhibition explanation for failure to find evidence of selective memory in anxious patients. By presenting some words before, and others after, instructions to forget, it will be possible to test the extent to which any differences are due to initial encoding effects, or to some later inhibitory process. The nature of any inhibitory effects that are found will be further investigated using implicit tests, such as anagram solution, to determine if priming effects persist for words that cannot be recalled, as suggested in section (B).

C2. Elaboration and Word Association: The hypothesis that inhibition results in impoverished links in memory between threatening and other types of information will be tested by Mathews and Milroy using word associations given to threatening or non-threatening cues. Subjects will be asked to generate as many different associates as possible to standard cues, with each associate being generated by going back to the original cue. Predictions for anxious subjects (relative to controls) are (i) absence of positive associates to threatening cues, (ii) successive associates to threatening words that are more similar in content to each other, and (iii) more identical associations to repetitions of a threatening cue.

The above predictions are based on the assumption that associations reflect automatic activation of related information in memory, and can thus be used to assess how this information is structured. However, they may also reflect the processing priorities in effect at the time. For this reason, associations will also be generated while subjects simultaneously carry out another task taking up attentional capacity (as in section A2). The former account would predict no effects due to divided attention, while the latter suggests that only under conditions of competition (and/or contextual priming) would the above predictions hold.

D. Instructional Control of Cognitive Processes Associated with Anxiety *(Mathews, Milroy)*

Although automatic processes are clearly implicated in the selective encoding of threat, it is very likely that intentional components are also involved, as suggested in (C1). It is proposed to investigate the role of these processes by testing the extent to which instructions or training can modify encoding operations characteristic of anxious versus non-anxious subjects.

D1. Consequences of Emotional Encoding: Subjects will be instructed to encode some words in terms of potential threat (e.g., What is the worst thing that this word suggests to you?), and to encode others non-emotionally. The words will then be tested for differences in capacity to capture attention and elicit perceptual priming. If the threat encoding instructions result in non-anxious subjects coming to respond similarly to anxious subjects, this would suggest that the relevant processes might be brought under intentional control.

D2. Consequences of Instructed Worry: In a previous study of worry (6.27), anxious and non-anxious subjects were asked to worry, suppress worrying, or think about an unrelated topic for five minutes, and thought content was sampled for the 20 minutes following. Anxious subjects always reported more negative thoughts, but there was a trend for suppression to result in more pleasant ideation. This paradigm will be used to establish a baseline for studying the cognitive consequences of instructed worry (e.g. on subjective risk), and to test the effects of training in different techniques to control excessive worry (e.g. by learning to generate reasons why the feared events may not happen).

E. Implicit Learning of Emotional Encoding Rules *(Mathews, Milroy)*

Explicit training may be a useful way to explore treatment implications, but is likely to be a poor model of any learning processes that might be involved in producing emotional encoding biases in anxious individuals. Anxious subjects often find it difficult to explain why they feel as they do, suggesting that any learning of encoding bias is implicit in nature. Biologically vulnerable individuals may acquire emotional encoding rules through exposure to event-outcome relationships, with the implicit rules being retained in memory in

schematic form, without subjects necessarily being able to report on them verbally. Two possible methods of investigating this hypothesis are being developed, both involving unobtrusive measures of text comprehension.
E1. Inferences in Emotional Texts: In the first method, subjects high or low in anxiety about particular situations (e.g. interviews) read texts describing threatening or neutral situations. The interpretation imposed by subjects is probed by speeded word decisions at critical points in the text. Data collected so far (by Colette Hirsch) suggest that probes requiring decisions about whether the offered word is a possible continuation of the text do show the predicted reaction- time differences between groups. This finding will be extended using different decisions (lexical, affective, etc.) and different types of emotional material.
E2. Implicit Learning of Emotional Associations: In the second method, subjects read a series of texts introduced by contextual settings that initially have no specific emotional meaning, but follow an implicit rule such that particular types of context are associated with either negative or positive outcomes. Subjects are later asked to imagine themselves in these contexts and then to rate how they feel at critical points. Pilot results show evidence of learning, in that contexts that have been associated with a positive outcome are then rated as more pleasant. However, the data so far are not definitive, being based only on subjective ratings, and because subjects can recall the emotional outcomes quite accurately. In further developments more objective probes will be used, together with longer delays, to test whether any effects persist in the absence of explicit recall.

COGNITIVE INVESTIGATIONS OF INSOMNIA *(Watts)*

Insomnia represents a very common condition, and a source of distress to a large proportion of the population. Recent years have seen a growing awareness that treatment by medication is not an optimal approach, and there has been increasing interest in psychological alternatives. The two most extensively researched forms of psychological treatment involve physical relaxation and behavioural (stimulus-control) methods. However, evidence from various sources indicates that the cognitive components of insomnia are particularly important. Surprisingly, in view of this, relatively little attention has so far been given to the development of cognitive treatments for insomnia. The project presented here had two main components: (a) a refinement and clarification of previous self-report studies of the cognitive factors important in insomnia; (b) the development of cognitive methods of treatment for insomnia.
The first psychometric study (6.9), designed to clarify the cognitive aspects of insomnia, took as a starting point a previously-developed sleep dissatisfaction questionnaire, but added additional items and administered it to a larger population. In this revised form, two distinct cognitive factors emerged, one relating to concerns about sleep, the other concerned with more general nocturnal mentation. The latter showed a strong correlation with general traits of worry and neuroticism, and was more prevalent in young insomniacs. To disentangle more clearly the role of worry in insomnia, a study was designed to examine in a 2 x 2 design subjects who were/were not worried and were/were not insomniacs (6.46). This study confirmed, in terms of the two different cognitive subscales of the sleep dissatisfaction questionnaire, that general worry, as measured by a standard psychometric instrument, predicted nocturnal mentation but not thoughts related specifically to sleep. In this study, another instrument was developed in which subjects were asked to complete

a check list in the mornings concerned with what they had thought about in any time during which they had been awake during the night. Again, there was a clear dissociation between concerns about sleep and other mental activity. Worriers showed more thoughts in almost every category except sleep, whereas insomniacs showed more thoughts about sleep, but hardly anything else. The kind of cognitive treatment most helpful for insomnia will probably depend on whether the predominant night-time thoughts are about sleep or other things.

A final psychometric study focused on insomniacs' sense of control over sleep (6.49). The fact that sleep is inherently difficult to control makes it a prime candidate for performance anxiety. As would be expected, insomniacs had less sense of control than other subjects. However, this sense of lack of control focused particularly on sleep itself rather than on pre-sleep drowsiness. Within pre-sleep states, the sense of lack of control focused particularly on mental activity rather than physical tension and arousal. It was also found that insomniacs' expectations of sleep were not based on the quality of sleep in recent nights, in the same orderly way as is found in controls. Most attributions of bad sleep are used more by insomniacs than non-insomniacs. One interesting exception is that poor sleep is frequently attributed to "heat and noise" by non-insomniacs, but seldom by insomniacs. Consistent with other research emphasising the importance of cognitive factors in insomnia, both insomniacs and controls regarded having an over-active mind as the most common explanation of insomnia.

The second part of the insomnia research has been concerned with the development of cognitive treatments. Particular attention has been given two main forms of intervention (6.17). One is a pre-sleep exercise in which subjects are required to identify, before going to bed, things they are likely to think about during the night, and to "put these to one side". This procedure seems to allow records to be tagged, in some way, as not requiring an immediate response. The result is that they are less likely to trigger the cognitive system into active processing when the subject goes to bed. It can be seen as analogous to the postponement approach to the treatment of worry developed by Borkovec, in which subjects identify worry topics and postpone concern with them. Another cognitive treatment, with a more explicit theoretical basis in Baddeley's working memory theory, involves a form of articulatory suppression to block intrusive thoughts which arise during the night. Our clinical work on the development of this technique suggests that, unlike laboratory articulatory suppression, it is best for the subjects just to think a blocking word such as "the", and also that they should 'repeat' the word at a relatively slow, relaxed speed. In working memory terms, we see this as taking up enough central executive capacity to disrupt thoughts that would otherwise interfere with sleep. When articulatory suppression becomes highly practiced, it can become less effective in blocking alternative thoughts. If this happens, there seems to be an advantage in adding an extra mental load, such as that involved in requiring repetition of the blocking word at randomly spaced intervals.

Work on this project has now been discontinued with Watts' move to the post of Starbridge Lecturer in the University of Cambridge.

COGNITIVE-AFFECTIVE INTERACTION IN DEPRESSION *(Barnard, Dalgleish, Teasdale, Williams)*

Introduction

Cognitive approaches have yielded both effective therapy procedures and new ways of understanding depression. Previous work has suggested that it is useful to think in terms of a reciprocal relationship between cognitive and affective components of depressive disorders; on the one hand, certain negative appraisals of experience may create or maintain depressed affect; on the other hand, depressed mood is associated with biases in memory, judgement, and interpretation that make such negative appraisals more likely. Such reciprocal relationships may act to maintain depressed states, and are reflected in the patterns of negative thinking characteristic of this disorder. Work in the current grant period has investigated further (1) the nature of cognitive-affective interaction in depression; (2) biases in interpretation and memory associated with depression; (3) the production of thought sequences related to negative thought streams; and (4) cognitive methods for treating and preventing depression.

A. Negative Thinking and the Maintenance of Depression

A1. Theory Development (Teasdale, Barnard): Better understanding of the interaction of cognition and emotion, and the clinical application of this knowledge, require theoretical frameworks that can integrate and explain the often complex findings of experimental studies and guide the application of these findings to the analysis and treatment of mood disorders. Over the last decade, Bower's (1981) associative network theory has provided the dominant theoretical framework guiding experimental investigations in this area, and Beck's (1976) cognitive model has informed clinical approaches. Recently, the weaknesses of these approaches have become more apparent (6.34, 6.69), as has the need for alternative conceptual frameworks.

We have devoted a major effort to the development, evaluation, application and communication of a new integrative theoretical approach to cognitive-affective interaction in both experimental and clinical contexts (6.1, 6.6, 6.34, 6.37, 6.70). This work has been presented most comprehensively in Teasdale and Barnard's book Affect, Cognition, and Change: Re-modelling Depressive Thought, published in October, 1993. This book: (i) provides a critique of Bower's and Beck's approaches to understanding cognitive-affective interaction in the area of depression; (ii) presents an extended description of a new, alternative, conceptual framework; (iii) applies this framework to an analysis of experimental findings on mood-related biases in memory and judgement, and shows that the new framework accounts for the detailed pattern of findings more satisfactorily than existing theories; (iv) presents a novel analysis of mood states; (v) describes a detailed analysis of the production of stimulus-independent thought, and of depressive thinking and its role in the maintenance of depression, testing these accounts against existing empirical findings; (vi) integrates the proposed analysis of the maintenance of depression with existing self-regulatory and motivational models of depression; (vii) contrasts the proposed account with Beck's, and shows how the new analysis resolves, within a precise, explicit theory, difficulties of earlier versions of the clinical cognitive model, and captures more recent, often imprecisely articulated, developments of that model; and (viii) applies the proposed analysis to the psychological treatment of depression, to provide a novel perspective on cognitive-behaviour therapy, and to suggest specific, testable hypotheses of the mediation of the short-term and long-term effects of this treatment. The considerable investment of effort in the theory development described in, and stimulated by, this book has been justified by the heuristic, guiding, and integrative function it has provided to the Unit's work in this area, and by the positive response it has already received more widely.

The new theoretical approach is an extension and elaboration of Barnard's (1985) Interacting Cognitive Subsystems (ICS) framework, and treats emotion within a comprehensive information processing framework. ICS distinguishes between representations at two levels of meaning. In addition to a specific, propositional, level of meaning, similar to that represented in Bower's associative network theory, ICS proposes a more generic, holistic level of meaning. At this level, schematic mental models encode high order themes and patterns of sensory information co-occurring across situations that, although superficially different, share certain "deep" commonalities. According to ICS, only this more generic level of meaning is directly related to affect; the synthesis of affect-related schematic models is the immediate antecedent to production of an emotional response, and such synthesis also underlies mood-related cognitive biases. Within ICS, reciprocal interactions and information exchanges between the cognitive subsystems that handle the two levels of meaning constitute a central feature of many aspects of cognitive processing, including the maintenance of affects associated with the subjective experience of streams of negative thoughts.

The distinction between two qualitatively different types of meaning, only the more generic of which is directly linked to affect, enables ICS to resolve many of the difficulties encountered by Bower's theory. Equally, Beck's original clinical cognitive model appeared to recognise only a single, propositional, level of meaning, and consequently encountered difficulties in explaining, for example, the contrast between "intellectual" and "emotional" belief, or the effectiveness of therapy procedures that provide no evidence for assessing the truth value of distorted beliefs. Application of the ICS account to understanding and treating depression from a cognitive perspective resolves many of these difficulties (6.1, 6.34, 6.71). It also suggests novel approaches to prevention (6.37) and provides guidelines for assessment in the treatment of recurrent mood disorders (6.70).

A2. Mood-State Dependency of Depressive Thinking: Changes in the Accessibility of Negative Constructs or Shifts in Schematic Mental Models? (Teasdale, Taylor): The elevated scores on measures of negative thinking of depressed patients in episode typically return to normal levels with recovery of euthymic mood. For example, although patients, when depressed, may express agreement with a statement such as "If someone dislikes me it means I'm no good as a person", they will express disagreement when the same item is presented after recovery. Teasdale and colleagues have examined competing explanations, offered by associative network theory and by ICS, for the mood-state dependency of such dysfunctional attitudes.

The Bower network model suggests that endorsement of dysfunctional beliefs when depressed reflects a general increase in activation and accessibility of negative constructs, such as "myself-as-a-no-good-person", that have previously been associated with the depressed state. As mood recovers, activation to this construct from the depressed state will reduce and so endorsement of the dysfunctional attitude is less likely.

By contrast, the ICS account suggests that changes in the endorsement of dysfunctional attitudes reflect a shift, with the move from one mood state to another, in high order mental models of self and world. In

depressed patients, it is suggested, the depressed state is associated with dysfunctional models, such as those implying that personal worth (or lack of it) depends on the approval (or disapproval) of other people. By contrast, the non-depressed state is associated with functional models that imply more independence of personal worth and the reactions of others. The focus of such schematic models is the inter-relationships between constellations of constructs rather than simply the level of activation of individual constructs.
Teasdale Taylor, Cooper, Hayhurst & Paykel (6.38) created sentence stems in which the dysfunctional models suggested by the ICS analysis would lead to completions by positive constructs, whereas functional models would lead to completions by negative constructs. For example, dysfunctional completions of the stem "Always to put others' interests before your own is a recipe for ___________" would involve positive constructs such as "happiness", whereas more functional completions would involve negative constructs such as "disaster". Using these stems, ICS makes the counterintuitive prediction that depressed patients will make more positive completions than non-depressed controls, and that, with recovery, there will be a decrease in the number of positive completions. By contrast, the associative network theory predicts that depressed patients will make more negative completions and this tendency will decrease with recovery. Results of a study in which patients with major depression were tested initially while depressed, and again three months later, supported the counterintuitive predictions of the ICS account. Similar results have been obtained in a subsequent study of depressed patients, and in a community sample of 99 depressed subjects recruited from a depressives' self-help organisation. Overall, these findings lend considerable empirical support to the ICS account of mood-dependent depressive thinking.
A3. Assessment of Affect-Related Schematic Mental Models: Reflecting the influence of the associative network theory of mood and memory, most laboratory paradigms in cognition and emotion research have focused on the level of individual constructs or representations of specific events. There is a need to develop new methodologies for the assessment of the affect-related schematic models that play a pivotal role in the ICS analysis.
A3.1. Contextual priming and assessment of affect-related schematic models (Teasdale, Taylor): Teasdale and colleagues have examined the utility of contextual priming paradigms, related to those used in studies of text comprehension, as methods for assessing affect-related schematic models.
In three studies, Teasdale and Taylor used computerised presentation of the sentence stems developed in A2 above. Each stem was presented twice, followed by words (matched for length and word frequency) that made either functional or dysfunctional completions (e.g. "Always to put others' interests before your own is a recipe for: survival/disaster"). Latencies to make decisions on functional versus dysfunctional completions to each stem were examined in relation to subjects' attitudinal models (assessed by self-report). Study 1 used a lexical decision paradigm, and found no significant differences in the relative latencies for functional and dysfunctional completions according to subjects' attitudinal models. Study 2 required subjects to make semantic decisions ("makes a meaningful completion or a meaningless completion?") and found significant effects; congruence between completion and attitude was associated with faster latencies. Study 3 included both lexical and semantic decision paradigms within the same experiment and again found significant effects with the semantic paradigm, but not with the lexical paradigm, the difference between the two paradigms being itself significant.

These studies suggest the usefulness of this novel form of contextual priming, using semantic decisions, as a measure of affect-related attitudinal models. Subsequent work has shown related paradigms to be sensitive to differences in intention-related representations (6.86) and to reveal differences between social phobics and normal subjects in their processing of threat-related passages (see Area 1, Proposals E1).

In studies of text comprehension, reading times for critical sentences in passages have been used to infer the nature of readers' mental models. In collaboration with Sheppard in the Cambridge University Department of Psychiatry, Teasdale has explored the usefulness of this strategy as a way of assessing the schematic models of depressed patients. Times to read sentences indicating positive or negative outcomes in scenarios involving themes of self-sacrifice or self-assertion were examined. Compared to controls, depressed patients took relatively longer to read sentences indicating positive outcomes in scenes in which they had sacrificed their own interests in order to win others' approval, but differences only appeared on the second presentation of the sentences. The results suggested that patients' schematic models created continuing processing priorities for thematically relevant material, but were not reflected in differences from normal subjects in the outcomes expected as the scenarios were read.

A3.2. Case grammar analyses (Barnard, Scott): Within ICS, the proposed generic and yet generative nature of schematic meaning has relatively clear consequences for the development of assessment techniques. Generic meanings, particularly those involving self-related constructs, may be highly variable in terms of the specific meanings they create, but should, nonetheless, show underlying systematicity in high level semantic abstractions. Schematic meaning can be explored by examining the abstract properties of "propositional" products which emerge over a range of expressed meanings. Potential abstractions of clinical relevance are likely to include dimensions such as being in control or being affected by events or other people. Interestingly, at least some of these dimensions map quite readily onto formal case grammar distinctions. These specify the general semantic roles that nouns may fulfil in relation to the main verb of a proposition. Examples for animate nouns are the "agent", "dative", "object", or "experiencer" case roles.

Initial investigations have provided evidence that case grammar classifications can be used to detect generic effects of this type. The Winicott Unit of the Department of Psychiatry in Cambridge made available protocol data of children describing the activity of their family in a doll's house play setting. The data were analysed for two groups -- children whose mothers had had a significant episode of post-partum depression (index group), and a control group of children whose mothers had no history of depression. Although the actual protocols were very heterogeneous in terms of surface form and content, case grammar analysis did reveal systematic differences in the generic properties of underlying propositional content.

The children in the index group consistently showed lowered reference to themselves in the "agent" role and an increased reference to themselves in the "experiencer" and, for girls, in the "dative" roles when compared to self-reference in comparable protocols obtained from the control group. Likewise, the index group used syntactic negatives far more often than the control group when referring to themselves. There were no such differences in case utilisation or negative syntax use between the index and control groups where reference was to siblings or parents. Children with markedly different patterns of early experience appear to develop quite different self-related schematic representations, with negativity and agentfulness being discriminative dimensions. The children of depressed mothers are at risk for later problems in affect regulation; and the properties on which differences have been detected bear an interesting relationship to those hypothesised to underlie depressive schematic representations. This is an important development which forms the basis for specific future proposals (section A3. below).

A4. Production of Stimulus-Independent Thought (Teasdale, Hutton, Lloyd, Taylor): Stimulus-independent thought refers to the streams of thoughts and images, with content quite unrelated to immediate stimulus input, that are often experienced when demands to process information from external sources are low. Production of stimulus-independent thoughts (SITs) in normal subjects has been studied for its inherent interest, and also as an analogue of the streams of negative thoughts that, according to cognitive models, contribute to the maintenance of depression. Teasdale and Barnard's analysis (6.1) suggests that production of SITs, in both normal and depressed subjects, depends on continuing cycles of interaction between the cognitive subsystems that handle, respectively, the schematic, model-based, level of representation and the level of representation corresponding to specific, propositional, meanings. Schematic models generate specific meanings, which feed back, in turn, to contribute to the production of further schematic models. According to ICS, similar cycles of reciprocal interaction between representations at these two levels subserve "central executive" functions, so that both thought production and executive control functions depend on the same processing resources, and would be expected to show mutual interference.

Earlier research, conducted within a working-memory framework, suggested that production of SITs depends on limited central executive resources of control and co-ordination. Subsequent studies have demonstrated interfering effects of memory load on SIT production and greater interference with thought production when task performance was associated with reports of high subjective awareness of task stimuli, and have suggested that interference is specific to connected sequences of SITs (6.36). Experiments have also specifically examined the hypothesis that SIT production and "central executive" functions compete for the same limited resources (6.35). This latter hypothesis makes the following predictions: (1) prior practice on concurrent tasks, by reducing the demands made on central resources for task control, will reduce the extent to which such tasks interfere with SIT production; and (2) if thought content is periodically sampled during a random number generation task, randomness (regarded as a paradigmatic indicator of central executive function) will be less preceding probes on which SITs are reported than preceding probes where no task-irrelevant thought is reported. Teasdale et al. (6.35) confirmed both these predictions.

Studies by Teasdale and colleagues have repeatedly found greater interference with SIT production when subjects report being highly aware of task stimuli than when they report being less aware, even when task performance is similar in the two conditions. These findings are consistent with the general suggestion that "controlled processing" is associated with greater awareness and interferes more with SIT production than more "automatic" processing. Subsequent studies have examined whether simply instructing subjects to maintain awareness on an attentional focus would, itself, interfere with SIT production. Teasdale and Hutton (6.60) found that instructing depressed subjects to keep their attention focused on their breathing reduced the frequency of negative thoughts. Teasdale and Hutton, in a subsequent study (6.61) instructed normal subjects to maintain an attentional focus on their breath and compared the thought contents reported at probes on which subjects indicated being highly aware and less aware of their breath. Results showed that stimulus-independent thoughts were reported less often at high awareness probes than at low awareness probes, but that stimulus-dependent thoughts were reported equally often in the two conditions. As well as pointing to differences in the processes underlying the production of these two types of thoughts, these findings are important because they suggest that the observed association between awareness and SIT frequency is not simply an artifactual consequence of the difficulties of attending to, or reporting on, both task and thought content. Rather, these results suggest that high awareness marks a type of processing, associated with the deployment of central executive resources, that interferes particularly strongly with production of stimulus-independent thoughts. These studies provide the basis of future work that will continue to investigate the effects of the breath-focus task in experimental and clinical settings.

B. Overgeneral Memory in Parasuicide and Depression *(Williams, MacLeod)*

This project, which ended when Williams moved to UCNW, Bangor, investigated the causes and mechanisms of a particular aspect of memory performance in emotional disorder. In Williams' previous work, he had found that suicidal and depressed patients show a deficit in autobiographical memory characterised by a difficulty in focusing on specific events. Such patients tend to give taxonomic categories of personal events (e.g., "going for walks", "being with my girlfriend"). The effect was not due to short-term mood disturbance, suggesting that it represented a longer-term cognitive retrieval style. During the period covered by this Report, the project investigated how this retrieval deficit contributes to hopelessness, problem solving and depression, and what mechanism might explain the phenomenon.

The research focused on the question of whether hopelessness and problem solving deficits were mediated by difficulty in generating specific images of the future. Williams predicted that such difficulty might arise because over-general retrieval of autobiographical events inhibits the use of specific memories in imagining such future events and in producing effective solutions to current problems. Consistent with this, Williams and colleagues found that parasuicide patients who have more difficulty in retrieving specific memories have greater difficulty in generating effective solutions on the Means-Ends Problem-Solving Test (6.14). Further, parasuicide patients with more problems in memory specificity produce less specific images of events that might occur in the future. Manipulating experimentally the retrieval style of normal subjects (generic versus specific) significantly affects the specificity of images of prospective events. In further work, Williams and colleagues in the Department of Psychiatry in Newcastle found that depressed patients who had more general autobiographical memory at admission were more likely to remain depressed seven months later (Brittlebank et al., 1993). These studies confirmed that this aspect of autobiographical memory is an important factor contributing to the maintenance of emotional disturbance.

Williams and Dritschel investigated the mechanisms underlying over-general retrieval (6.78). Previous work had assumed that patients were accessing an "intermediate description" in memory retrieval, but were stopping short of a specific example. While the general notion of a hierarchical search strategy remained useful, the theory made no distinction between different types of hierarchy a person might use. Williams and Dritschel distinguished two forms of super-ordinate memory. The first, categoric memory refers to descriptions containing generic summaries of events (such as "drinking in pubs"). The second, extended memories refers to descriptions containing extended event time lines (such as "my first term in Oxford"). The significance of the distinction is that, whereas categoric memories are useful in summarising a number of similar situations, a nested structure of extended memories is necessary to orient people in space and time, and to keep people up to date in relation to both short-term and long-term goals. Williams and Dritschel found these two forms of intermediate description to be independent from each other, and that only categoric memories correlated with neuropsychological tests of Supervisory Attentional Control. Further, they found that excessive overgeneral memory in emotional disturbance is associated only with an excess of categoric memories but no increase in extended memories (6.78). A project still in progress on elderly people with dementia has found a significant association between severity of general cognitive deficit and categoric memories but not extended memories, providing further confirmation of the independence of these types of overgenerality in memory.

These results have important implications for the treatment of emotional disorders (Scott et al., 1989; Williams & Wells, 1989; Williams, 1992). Many psychotherapeutic strategies depend upon the ability of patients to retrieve specific events from the remote or recent past, or to keep diaries of day-to-day events. Current research is examining the prediction that effectiveness of psychotherapies will in large part be determined by how well they are able to encourage the recollection of specific events. Such specific retrieval predicts good outcome because it allows the recoding of depressive interpretations of the past and the construction of more specific images of the future, and because it enhances problem-solving skills.

C. Prevention of Relapse and Recurrence in Depression *(Teasdale)*

Prevention of relapse and recurrence in depression has been identified as an R and D Priority Area by the Department of Health. There is encouraging evidence for prophylactic effects of a psychological treatment, cognitive therapy. In collaborative studies, funded by external grants, Teasdale is investigating the effectiveness and mode of action of cognitive therapy, and developing new forms of preventive treatments that operate through related mechanisms. His participation in these projects has involved elaboration of the ICS theoretical perspective on treatment and prevention (6.1, 6.37, 6.71) and provides an opportunity to examine the validity of these hypotheses.

C1. Cognitive Therapy for Residual Depressive Chronicity: In collaboration with Paykel in the Cambridge University Department of Psychiatry and Scott in Newcastle, Teasdale is involved in a controlled clinical trial, investigating the short-term and long-term (prophylactic) effects and mode of action of cognitive therapy in patients who still have residual depressive symptoms after an adequate trial of anti-depressant medication. Recent research in Cambridge suggests that this group has a poor long-term outcome with existing treatments: 78% had relapsed within 9 months of discharge. The trial compares the combination of anti-depressant medication and clinical management to this combination plus cognitive therapy. To investigate the mediation of effects of cognitive therapy, new cognitive measures have been developed, and are being administered in addition to measures suggested as important in previous studies. For example, Teasdale's theoretical analysis (6.1, 6.67, 6.71) suggests that cognitive therapy operates through (a) reducing patients' perception of depression as evidence of their personal inadequacy and (b) increasing their perceptions of control over depression. Measures to assess these variables have been developed on a group of 250 depressed volunteers from the organisation Depressives Associated, and have been shown to possess excellent internal consistencies (Cronbach's alphas > .93). This large data set is also being used to examine, through structural modelling techniques, the relationship of these variables with measures of dysfunctional attitudes and of global negative self-schema that have been shown to predict outcome in previous studies. Further measures and their underlying rationale are described in Proposals C1.

Patient entry into this trial began in April 1994, and the project will be completed in January 1998.

C2. Attentional Control Training to Prevent Depressive Relapse: There is encouraging evidence for the effectiveness of cognitive therapy in reducing the risk of relapse (or the need for further treatment). Cognitive therapy in its present form, however, depends on extensive individual contact with highly trained therapists; therefore, even if its prophylactic effects are confirmed by further studies, it may not be available to more than a small proportion of the very large numbers of patients who might benefit. In collaboration with Williams (UCNW, Bangor) and Segal (Clarke Institute of Psychiatry, Toronto), and with support from the MacArthur Foundation, Teasdale has been developing and piloting a novel cost-efficient approach to psychological prophylaxis for depression - Attentional Control Training (ACT). Based on a theoretical analysis of relapse and its prevention (6.1, 6.37), ACT is designed to produce prophylactic effects similar to those of cognitive therapy, using skills-based group training in patients who have recovered from their acute episode following conventional treatment by anti-depressant medication. The treatment procedure combines aspects of cognitive therapy with training in attentional control skills similar to those included in a stress-reduction programme developed by Kabat-Zinn at the University of Massachusetts, for which there is promising evidence of effectiveness in the treatment of chronic pain, anxiety and panic, and other stress-related disorders (e.g. Kabat-Zinn et al., 1992). A preliminary treatment manual has been produced (6.87), and pilot groups in Toronto, Bangor, and Bury St. Edmunds have demonstrated the acceptability of this approach and provided encouraging clinical evidence for the utilisation and effectiveness of the skills taught.

FUTURE PROPOSALS

Introduction: Schematic Models and Central Executive Resources in the Maintenance and Regulation of Affect

The aim of work in this area is to increase our understanding of processes related to the maintenance and regulation of affect in situations where otherwise transient affective states may escalate and persist to become disabling emotional disorders. This knowledge will be applied to the development of more effective and efficient methods for reducing relapse and recurrence in depression. These proposals are based on the theoretical analysis of (neurotic) depression developed by Teasdale and Barnard in the current grant period. This analysis suggests that depression depends on the synthesis of schematic representations that encode the high order themes and recurring sensory patterns extracted from previous depressing experiences. The maintenance (and escalation) of depression depends on the continuing regeneration of such affect-related schematic mental models. Often, particularly in states associated with reports of streams of negative thoughts, this regeneration will be the result of self-perpetuating cycles of cognitive activity. These cycles, it is suggested, depend on the same "central executive" resources that are also required for many other tasks involving "controlled processing". As these resources are limited, mutual interference between affect maintenance and other aspects of "central executive" functions would be expected. In these circumstances, affect regulation can be achieved by re-allocating limited central resources to process information that will not perpetuate affects. Such reallocation, it is suggested, depends on changes in the "schematic-model-in-place" that, from moment to moment, sets the priorities for control resources to process different classes of information. Affect regulation in such situations can be improved by training individuals in attentional skills that, effectively, give them greater control over the "schematic-model-in-place", and so allow them to switch out of the cycles that might otherwise escalate or maintain depression. The availability of affect-related schematic models in memory will be an important factor influencing the ease with which this switching can be achieved or maintained.

Work in this area has the following objectives. First, it is important to extend our understanding of the nature of depression-related schematic models and the ways that they influence thinking. Second, the proposal that maintenance of certain affective states depends on limited cognitive resources that also subserve "central executive" functions will be subjected to detailed examination. Third, the effects of attentional training on the ability to redeploy central resources from affect-related processing, and the involvement of such resources in affective "re-appraisal", will be examined. Finally, the application of the proposed theoretical analysis to the prevention of relapse and recurrence in depression will be examined in the context of investigations of the prophylactic effects of an existing treatment (cognitive therapy), and of the development of cost-efficient methods of attentional control designed to achieve similar effects.

A. Affect-Related Schematic Models, Central Executive Resources, and the Maintenance of Mood

A1. Schematic Mental Models and Reasoning in Depression (Dalgleish): Relatively little experimental work has examined biases in higher-order cognitive processing, such as reasoning and decision-making, in depression. The theoretical model described by Teasdale and Barnard (6.1) suggests that reasoning depends on iterative cycles of interaction between representations at the schematic mental model level and at the level of more specific propositional meanings. This analysis suggests that, in depressed patients, aspects of the affect-related schematic models maintaining depression may become incorporated into the mental models used to generate and evaluate candidate propositional meanings as solutions to reasoning tasks. It follows that performance on reasoning tasks involving different types of content can be used to draw inferences concerning the schematic mental models associated with the maintenance of depression, and to compare the strength of the biases resulting from such affect-related models with those resulting from more "factual" (affect-unrelated) models. Dalgleish will exploit this possibility to investigate the hypothesis that biases in reasoning are greater when processing emotional material that is inconsistent with the affect-related mental models (assumed to be involved in the maintenance of depression) than when processing non-emotional material that is inconsistent with "factual" mental models, unrelated to affect. Consider, for example, two statements that might contradict the models of the world of a depressed individual:

1) Elephants are bigger than mountains

2) My neighbour is more worthless than I am.

The first statement contradicts a factual model of the world, whereas the second statement contradicts an affect-related model of the world (i.e., a model which might give rise to statements such as "I am more worthless than anyone I know"). Dalgleish will examine the performance of depressed subjects on reasoning problems that require them to generate such statements as answers, for example:

1) The elephant is bigger than the mouse

The mouse is bigger than the mountain

Which is biggest (elephant or mountain)?

2) My neighbour is more worthless than my postman

The postman is more worthless than me

Who is most worthless (me or my neighbour)?

It is predicted that depressed subjects will show greater differences (in terms of speed of processing or error rate) from normal controls on the second type of syllogism (which contradicts a depression-related world model) than on the first type of syllogism (which contradicts a world model unrelated to affect). It is predicted that normal controls will also experience difficulty solving syllogisms that cause them to generate conclusions that contradict affect-related models of the world. However, the syllogisms will be different than for depressed subjects; for example, a syllogism that required them to conclude that they were more worthless than their neighbour would pose difficulties for normal subjects. If the predicted results of this initial study are obtained, subsequent studies would examine the extent to which such effects are mood dependent using mood induction procedures.

A2. Assessment of Affect-Related Schematic Models (Barnard, Scott): Extending the application of the ICS framework to maintenance, regulation, and control of affect requires further advances in our understanding and assessment of the schematic organisation of self-related meaning. This form of meaning is assumed to be generic in nature and built up from information with propositional, sensory and proprioceptive origins. Three lines of future enquiry are proposed, all of which will focus upon schematic organisations of meaning related to core constructs of the self ("self-related models"). Each requires the systematic, but exploratory analysis of protocol data using case grammar techniques. The first line of enquiry concentrates on the developmental form and content of self-related models, the second introduces an emphasis on tracking changes in schematic processing with alterations of mood state, whilst the third line emphasises transient sensory influences. The first two rely upon established external collaborative links for the provision of the data to be analysed.

The first line of enquiry is a direct extension of the recent work with children and involves two stages. In the first stage, the immediate question concerns the generality of the initial results suggesting that the children of depressed mothers develop markedly different models of the self than the children of mothers who do not suffer a period of depression. With our support, the Winicott Unit has undertaken to analyse a much larger sample of protocol data from 5 year olds. In this way the generality of earlier findings can be tested and the robustness of the case grammar analysis can be assessed and, where necessary, refined. In the second stage, the questions of interest concern (a) the stability over time of the children's self-related models and (b) the extent to which the detailed form and content of these models predict predisposition to later cognitive-affective dysfunction. It is proposed to obtain verbal protocols from the same cohort of children at age 8 in a setting directly comparable to doll's house play. The case grammar profiles will be related to a variety of behavioural and affect related indices. If a lowered sense of agency and heightened negativity are essential aspects of depression-related schematic models, then their influence should be apparent in behavioural or self-report indices. The logistics for this strand of research are all specified in a recently awarded MRC Programme Grant to the Winicott Unit (Murray & Cooper) on which Barnard is a named collaborator.

The analysis proposed by Teasdale & Barnard (6.1) holds that self-related models differ between clinical and normal populations. The analysis also holds that affect regulation within the same individual depends upon the particular "schematic-model-in-place" and that these can switch over time. The second line of enquiry involves applying the case grammar technique to compare the self-related models of depressives in different mood states with those of control subjects. For an initial pilot, the Winicott Unit have agreed to make available data from adult attachment interviews involving a sample of normal mothers, a sample of depressed mothers where the interview was actually obtained during a depressive episode, and a sample of mothers who have experienced a period of depression but who were not depressed at the time of the interview. If the case analysis of these data reveals systematic differences between these adult groups, then it would confirm the sensitivity and potential utility of the technique. For subsequent work, it is proposed to focus upon patients with bipolar affective disorder, whose mood state swings radically from depression, through neutral, to mania. Informal clinical observation suggests that generic features of the case analysis -- those of agency and negativity as applied to the self -- change radically with the change of mood state evidenced in these patients. The empirical work would be carried out in collaboration with Ann Palmer of the Norwich Clinical Psychology Department, who has agreed to provide the basic protocol data for case grammar analysis. Should this form of investigation prove productive, existing collaborations could readily support extensions to several other populations including other classes of depressives, certain anxiety conditions, and schizophrenics (see also the Programme on Attention and Cognitive Control).

The third line of enquiry asks the question: Under what conditions can properties of the "schematic-model-in-place" be modified or even switched completely under the influence of direct external sensory information? Recent research has made use of computer controlled video, voice and facial animation to assist in the elicitation of verbal protocols (for example in obtaining assessments of computer-based tutoring and learning systems). Normal peoples' responses are systematically influenced by both voice characteristics and facial expressions. Attributions of agency in the context of computer-based dialogues (Nass et al., 1994) can vary quite markedly depending on whether the questions are asked by the same computer agent ("self") or a different computer agent ("other"), and this can be signalled by the "voice" of the computer agent itself. Likewise, enquiries made by a "stern" computer animated face lead to lengthier and more detailed replies than responses to a neutral face, but are less likeable experiences for the respondent (Walker et al., 1994). It is proposed to capitalise on APU skills in HCI research to pilot work on the computer-based presentation of full face agents to elicit protocols on topics related to the self or to others. Voice and expression will be varied, possibly in conjunction with other well-established mood manipulations such as the Velten procedure. The effect of these manipulations on the protocols elicited will be examined using case-grammar techniques, effectively providing an opportunity to examine the effects of specific experimental manipulations on the schematic models assumed to mediate the observed changes in behaviour. Use of computer facilities for presenting faces may share key technical resources with work on facial expression being proposed by Young (Cognition and Emotion Area 4).

Within the linguistic literature the semantic notion of agency is itself rather complex, involving elements of control, causality and change (e.g. see Schlesinger, 1992). In addition, nouns obviously occur in quite different case frames depending upon the specific class of verbs involved. Interestingly, similar general themes, including perceived controllability and persistence, recur in the literature on depression (e.g. 6.67) or anxiety conditions such as PTSD (Foa & Riggs, 1993). By systematically developing and refining the application of the case constructs to the protocol data, we hope to develop more precise practical techniques for representing the form and content of self-related models as well as developing a closer synergy between cognitive-linguistic concepts and the terminology of clinical practice.

A3. Affect Maintenance and Central Executive Resources (Teasdale, Hutton): Affective states associated with streams of negative thoughts (depressive ruminations) often persist in the absence of immediate sensory input from actual affect-inducing events. Teasdale and Barnard's theoretical analysis suggests that the maintenance of such states depends crucially on the processing of affect-maintaining information by the same cognitive resources that subserve the control and co-ordination functions often ascribed to a "central executive". To date, support for this central aspect of the proposed account has been largely indirect: for example, studies of stimulus-independent thoughts in normal subjects have been used as analogues of the streams of negative automatic thoughts in depression. Teasdale and Hutton will conduct a series of studies specifically examining the hypothesis that maintenance of affects associated with negative thought streams depends on cycles of cognitive processing (marked by reportable negative stimulus-independent thoughts) that require central executive resources of control and co-ordination. Studies will focus on populations scoring high on the personality dimension of neuroticism, as these subjects have a heritable predisposition to affective lability that puts them at enhanced risk of affective disorders such as major depression. Subjects will also have to demonstrate evidence of the ruminative response style (Nolen-Hoeksema, Morrow & Fredrickson, 1993) associated with elevated risk for persistent depression.

The investigative strategies will be based on those that have already been successfully employed in studies of stimulus-independent thoughts in normal subjects. Future investigations will take advantage of methodological improvements in the assessment of central executive functions, and will assess affective state as well as the mental contents sampled at thought probes.

Using the random finger movement task, recently developed at the APU, as a measure of central executive function, the following predictions will be tested:

(1) Randomness of finger presses will be lower prior to thought probes on which negative thoughts are reported than on probes with no task-irrelevant thoughts. This prediction is based on findings showing an inverse relationship between randomness in number generation and the occurrence of stimulus-independent thoughts in normal subjects (6.35).

(2) With continuous on-line measurement of randomness of finger presses to determine when to probe for thoughts, negative thoughts (and momentary negative mood) will be more likely at times when randomness is low than when it is high.

(3) Extent of mood improvement during performance of the randomness task will be related to the extent to which random performance has been achieved.
(4) Negative thoughts will be less likely at probes where subjects report greater subjective awareness of task stimuli than at probes where subjects report less awareness; this effect will be greater for stimulus-independent thoughts that are parts of connected sequences than for fragmentary thoughts, and will be greater for stimulus-independent thoughts than for stimulus-dependent thoughts. These predictions are based on, and extend, previous findings on stimulus-independent thoughts in normal subjects (e.g. 6.36).
(5) With pursuit rotor and memory tasks, prior practice on a task (assumed to reduce the central executive resources required to control task performance) will reduce the extent to which the task interferes with negative stimulus-independent thoughts, and the extent to which it alleviates negative mood. Teasdale et al. (6.35) report related findings in normal subjects.
A4. Working Memory and "Re-Working" Affect-Related Schematic Models (Teasdale, Hutton): Depressed patients show greater evidence of the influence of dysfunctional schematic models than normal controls. It is possible that depressed and normal subjects may differ, not so much in the schematic models synthesised initially, but in the extent to which these models, and their products, are re-worked or re-appraised by subsequent controlled processing, requiring central working memory resources. If this is the case, normal subjects in whom working memory resources are occupied by a concurrent task, such as a memory load, would be expected to show evidence of the effects of dysfunctional schematic models, similar to that shown by depressed patients.
In preliminary studies, Teasdale and Hutton have found that a concurrent digit load increased the number of dysfunctional completions made by normal subjects on a sentence completion task, previously developed specifically as a measure of dysfunctional models. Under a cognitive load, the performance of normal subjects approximated more closely that shown by depressed patients. Further, the effects of having completed the sentence test under a digit load persisted after the load was removed; subjects re-tested immediately afterwards, with no load, still showed elevated levels of dysfunctional completions. Such persisting effects could be abolished if, prior to completing the sentence task, subjects were asked to rate the extent to which they agreed or disagreed with statements such as "My value as a person depends greatly on what others think of me" from the Dysfunctional Attitude Scale (DAS) (Weissman & Beck, 1978). The effects of such prior experience were not observed in subjects who responded to DAS items while under a concurrent digit load. The pattern of results suggests that re-working of the initial products of dysfunctional models, using central working memory resources, may be an important factor in the functional thinking of normal subjects. The results also suggest that the effects of recent schematic processing can continue to influence subsequent performance, presumably through effects of priming or accessibility of stored representations in memory. The finding that the effects of recently producing dysfunctional completions can be undone, but only if controlled processing resources are currently available and there is a history of recently processing related material with full access to working memory resources, is particularly interesting. Presumably, subjects who had previously responded to DAS statements without a load had had the opportunity to evaluate, and re-evaluate,

dysfunctional models as they completed the DAS. These re-worked models were then available to influence subsequent processing, but only did so if controlled processing resources were also available.

These preliminary findings are consistent with the possibility that functional thinking in normal subjects may depend, at least in part, on the re-appraisal of initially synthesised dysfunctional models. Such re-appraisal appears to depend on the availability of (central) working memory resources and the availability, in memory, of representations of related, but modified, schematic models. This possibility is directly relevant to our interest in the role of controlled processing resources, and the availability of representations of modified schematic models, in the maintenance and regulation of affective states (see B and C below). In further studies, Teasdale and Hutton will examine the replicability of these preliminary findings, and employ parametric studies to examine factors such as the nature of the DAS items presented (functional versus dysfunctional; closely versus distantly related to the models assessed by the sentences), the interval between the encoding and test phases, and effects in subjects in whom dysfunctional models are more salient.

B. Attentional Control and Affect Regulation *(Teasdale, Hutton)*

Teasdale and Barnard's theoretical analysis (6.1) suggests that the maintenance (and escalation) of certain affects depends on self-perpetuating cycles of cognitive processing. Such cycles, it is proposed, depend on limited "central executive" processing resources, and are controlled by affect-related schematic models. In this situation, affect regulation can be achieved by using supervisory attentional functions (Norman & Shallice, 1980) to re-allocate limited central resources to process information that will not perpetuate affects. Teasdale and Barnard's analysis also suggests that lasting effects of affect-regulation depend on creating, or accessing from memory, alternative schematic representations of affect-related material; otherwise, representations of the original, affect-maintaining, models may be accessed from memory and redirect processing back into affect-perpetuating cycles.

High subjective awareness of task stimuli, or of an attentional focus such as the breath, marks a form of processing that is particularly effective at disrupting streams of stimulus-independent thoughts. If we accept the suggestion that such awareness indicates the deployment of central resources to the processing of current task or sensory content, rather than thought content, these findings suggest that procedures which train subjects to maintain subjective awareness of current experience may be useful as a way of regulating affects associated with streams of negative stimulus-independent thoughts.

Such a programme has been developed and evaluated by Kabat-Zinn and colleagues at the University of Massachusetts Medical Center (Kabat-Zinn et al., 1992), and includes training in : 1) maintenance of an attentional focus (e.g. awareness of the breath); 2) detection of loss of awareness and wandering from that focus to thoughts and feelings; 3) recognition of those thoughts and feelings as mental events rather than the "realities" that they represent; and 4) the re-direction of attention back to the focus of awareness.

In a theoretical analysis of this programme, Teasdale, Segal and Williams (6.37) have identified two central aspects: 1) continuing high subjective awareness of the attentional focus marks deployment of limited central processing resources to that topic rather than to competing demands, such as the cognitive cycles that maintain affects; 2) awareness of thoughts and feelings as "mental events" depends on, and contributes to, the creation of modified schematic models. Such models, although related to the same topic as the schematic models driving affect- or intention-related processing cycles, are sufficiently different from those models that subsequent processing is re-directed out of affect-maintaining configurations. This analysis suggests that the effects of such programmes will be different from those of simple distraction procedures. Both approaches, by taking over central resources that are required for affect maintenance, may lead to concurrent alleviation of mood. However, it is predicted that the attentional re-focusing procedure, involving the creation and storage of modified schematic models, will lead to more enduring effects. In particular, it is predicted that, following the period of active distraction or attentional re-focusing, it will be easier to avoid the re-establishment of affect-maintaining cycles following the more elaborate procedure.

These predictions will be tested with respect to the maintenance of states of negative self-focus that, according to self-regulatory models of depression (e.g. Pyszczynski & Greenberg, 1987), maintain the depressed state. Negative self-focus is assumed to involve repetitive (unsuccessful) cycles of processing motivated to reduce the discrepancy between representations of current self-related outcomes and representations of intended goal states for those outcomes. This formulation shares many features with the analysis of the maintenance of depression proposed by Teasdale and Barnard.

Teasdale and Hutton will test the following predictions in studies on (high neuroticism) subjects with high trait levels of negative self-focus: 1) focusing attention on an aspect of the self (the breath) will, somewhat counterintuitively, lead to reductions in self-focus similar to those reported with external distraction; 2) following the breath focus procedure, compared to the distraction procedure, reductions in negative self-focus will persist longer, processing priorities for self- and depression-related information will be reduced more, and related stimuli will, subsequently, be less likely to "recapture" attentional resources. These predictions will be examined following different durations of breath focus and distraction, each preceded by varying levels of prior practice. Negative self-focus will be measured using memory and production tasks shown to be sensitive to changes in negative self-focus in published studies, as well as measures of self-related and depressive content in the stream of spontaneous thought. Effects on processing priorities for depression- or intention-related material will be examined using a) incidental encoding and reading time measures for material that is specifically related to depressogenic models, depressive self-guides (Higgins, 1987), and ruminative sentences (Nolen-Hoeksema, Morrow & Fredrickson, 1993); and b) measures of capacity to sustain attention to non-affective stimuli in undemanding experimental situations. For example, it is predicted that the breath focus task will lead to greater reductions in reading times for sentences expressing (individually relevant) ruminative thoughts such as "Why do I have problems that other people don't seem to have?" and will reduce the extent to which such sentences evoke further ruminative content in subsequently sampled thought streams.

If the predicted differences emerge, the specific contributions of different aspects of the breath focus task will be examined. For example, the importance of recognising thoughts and feelings as "mental events" could be examined by comparing two versions of the task. In one, subjects, after acknowledging and recognising the nature of the thought streams and feelings to which their attention has strayed, will re-direct their own attention back to their breath, as in the conventional procedure. In the other, subjects will be periodically signalled to return attention to the breath without any requirement for self-monitoring. Similarly, the contribution to the breath focus task from its emphasis on "direct" processing of immediate experience, rather than on discrepancies between such experience and intended outcomes, could be examined by comparing versions of the task that emphasise the former features with versions that emphasise goal-orientation and performance standards for maintaining the attention focused on the breath.

The results of the experimental studies in this section will provide detailed guidance for the development and assessment of improved clinical programmes of attentional control training (C2).

C. Prevention of Relapse and Recurrence in Depression *(Teasdale)*

The strategic importance, existing collaborations, and clinical background to work on this project were described in Section C of the report of previous work. The theoretical background to this work (6.1, 6.37) is based on previous studies showing that individuals who have recovered from depression can be distinguished from those with no history of depression in the patterns of negative thinking that become activated in states of mild negative affect; recovered patients are more likely to show patterns similar to those observed in episodes of major depression. Such evidence suggests that relapse may depend on the re-activation, in situations of dysphoria or environmental stress, of the depressogenic cognitive cycles, dependent on central executive resources, that were active in the preceding episode of depression. On this view, psychological prophylaxis involves the "normalisation" of the thinking patterns that become activated in these situations in vulnerable individuals. This can be achieved, it is suggested, by arranging repeated experiences in which patients synthesise modified (non-depressogenic) depression-related schematic representations in many different potentially depressing contexts. In this way, patients have available in memory a store of modified schematic representations that can be accessed in preference to depressogenic representations at times of potential relapse, so preventing the re-establishment of depressive thinking patterns.

C1. Cognitive Therapy for Residual Depressive Chronicity: Teasdale will continue to be involved in a collaborative clinical trial (end date 1.2.1998) evaluating the short-term and long-term (preventative) effects of cognitive therapy for patients who still show residual depressive symptoms following an adequate trial of anti-depressant medication. The cognitive mediation of any prophylactic effects obtained will be examined by including, in addition to cognitive measures to replicate findings reported in previous trials, measures specifically developed to test the theoretical analysis described above: 1) a measure of the availability, in memory, of representations of depressing situations to which patients have responded with evidence of coping and awareness of negative thoughts and feelings as "mental events" (cf. A4) and 2) a measure of the extent to which negative cognitive patterns related to a globally negative self-view are activated in depressed moods. It is predicted that cognitive therapy will reduce these measures more than the comparison condition, that post-treatment scores on these measures will predict relapse over the follow-up period, independently of the prediction from post-treatment severity of depression, and that prophylactic effects of cognitive therapy can be accounted for, statistically, through effects on these variables.

It is anticipated that, if this trial suggests positive effects of cognitive therapy, an application will be made for external funding for a further trial to examine the relative effectiveness of cognitive therapy and alternative psychological treatments. Such a trial would provide an opportunity to investigate further the conclusions concerning therapeutic mechanisms emerging from the present trial.

C2. Attentional Control Training to Prevent Depressive Relapse: Teasdale will continue collaborative work to develop and evaluate Attentional Control Training, a novel cost-efficient approach to psychological prophylaxis for depression, specifically designed on the basis of an analysis of relapse and its prevention that he and his collaborators have proposed (6.37). The treatment procedure (6.87) combines aspects of cognitive therapy with a form of training in attentional skills similar to those studied experimentally in B, and fruitful interactions between work in these two projects is anticipated.

Further development work will depend on a continuing collaboration with Williams, Segal, and Kabat-Zinn, and extra travel costs to facilitate liaison with these workers, and to attend a training course at the Stress Reduction and Relaxation Program, University of Massachusetts Medical Center, are requested.

It is anticipated that, following further development work and pilot evaluations, external funding will eventually be sought for a randomised controlled trial. This will evaluate the prophylactic effects of Attentional Control Training in patients with at least one prior episode of major depression who have recovered from their current episode following treatment with antidepressant medication.

RECOGNITION OF EMOTION *(A Young)*

Introduction

Young having joined APU in September 1993, this progress report is effectively based on 6 months work.

An important component of any emotional behaviour is how we interpret the moods and feelings of other people. A central claim of theoretical approaches to face processing developed in the 1980s was that different neural mechanisms are involved in recognition of a face's identity and determining its emotional expression (Bruce & Young, 1986), and that these proceed in parallel, to a large extent independent from each other. The evidence to support this position was, however, limited and incomplete. A main focus of recent work thus concerns the processing of facial expressions, and how this relates to the processing of identity. The work follows directly from studies completed or initiated at the University of Durham (Young, Newcombe, de Haan, Small & Hay, 1993a), and has involved both neuropsychological studies and laboratory experiments. A subsidiary interest is in malfunction of emotional mechanisms in cases of delusional misidentification.

A. Neuropsychological Impairments *(Young, Aggleton)*

Joint work with Dr. John Aggleton (University of Durham) involves detailed investigation of face processing abilities in a woman with a severe impairment of expression-processing after amygdalotomy, exploring her ability to match the same set of stimuli on identity (intact) and expression (impaired). The interest of this finding is that, although it is often claimed that there is a double dissociation between neuropsychological impairments affecting the processing of facial expression and identity, few studies have looked in any detail at selective impairments that compromise the recognition of facial expressions.

B. Experiments with Normal Subjects *(Young, Calder, Etcoff, Perrett)*

A current project is exploring categorical perception of identity and expression, using computer-generated blends of different faces (joint research under an existing ESRC grant; with Dr. Andy Calder, University of Durham, Dr. David Perrett, University of St. Andrews, and Professor Nancy Etcoff, Massachusetts Institute of Technology). Categorical perception is said to occur when people are more sensitive to changes which lie across a boundary between two perceptual categories than they are to changes of the same physical magnitude within a perceptual category. This can arise because a common requirement in perception is to assign the things we see or hear to discrete categories, which simplifies the task of interpreting what is happening and selecting appropriate actions. Previous work by Etcoff and Magee (1992) had shown categorical perception of facial expressions with line drawings. The current research is exploring categorical perception using images depicting facial continua (expressions, familiar and unfamiliar identities, age, and sex) in photographic quality. The stimuli and findings are likely to have applications in future neuropsychological studies.

C. Delusional Misidentification *(Young, de Pauw, Ellis, Hellawell, Reid, Szulecka)*

A second topic of current interest involves the link between face processing impairments and delusional misidentification, with particular reference to the Capgras delusion (with Professor Hadyn Ellis, University of Wales College of Cardiff, Drs. Karel de Pauw and Dr. Krystyna Szulecka, Doncaster Royal Infirmary, and Dr. Ian Reid, University of Aberdeen). Here, the aim is to determine whether the general approach used in cognitive neuropsychology can usefully be extended to delusions and related 'psychiatric' phenomena. In cognitive neuropsychology, a model of normal performance is used to account for different types of impairment; at issue is whether this will also prove fruitful for delusions. Delusional misidentification has been chosen as a starting point because a reasonably articulated theoretical model of normal face processing and appropriate tests are available.

The Capgras delusion involves the belief that familiar people have been replaced by 'dummies' or impostors. Ellis and Young (1990) explicitly made a link to work on covert recognition in prosopagnosia (Young, 1993; Young and de Haan, 1992), suggesting that the Capgras delusion might usefully be seen in part as a mirror-image of the problem found in prosopagnosia. For prosopagnosic patients, the face is not recognised overtly but some automatic reactions, including those involving its emotional significance, are typically preserved. In Capgras cases, the face is recognised but its emotional significance is lost. A review of these areas has recently been completed (Young, 1994), and the idea has been further developed into the proposals (a) that the Capgras delusion represents the patient's attempt to make sense of the fact that visual stimuli no longer produce appropriate affective responses, and (b) that the genesis of this delusion therefore involves an interaction of impairments at two levels (6.32). One set of contributory factors create anomalous perceptual experience, and the other factors lead to an incorrect interpretation of this experience, with misattributions due to suspiciousness playing an important role (Wright, Young & Hellawell, 1993; Young, Reid, Wright & Hellawell, 1993).

FUTURE PROPOSALS

Introduction

The general direction of the work is towards examining expression processing and social perception in more detail. A continuing concern involves the relation of the recognition of identity and expression from the face. This will be explored by attempting to fractionate components of emotional expression perception, using an approach that combines studies of neuropsychological cases and experiments with normal people, along the lines adopted in previous work on the recognition of identity. In addition, the relation between the processing of facial and vocal expressions will be investigated.

For these purposes, specific planned projects are case studies of bilateral amygdalotomy, an investigation of face processing impairments after frontal lobe lesions, and studies of priming effects on the recognition of facial expressions.A separate area of further work concerns cognitive and emotional components of delusions, and especially delusional misidentification.

A. Neuropsychological Impairments*(Young, Aggleton)*

The significance of planned work on the neuropsychology of expression perception is that it will try to identify precisely the functional locus of observed deficits and clarify whether facial expression processing is implemented by neural mechanisms which are face-specific or supramodal, and whether these are emotion-specific or used in all forms of social interaction.

A1. Case Studies of Amygdalotomy: The case studies of amygdalotomy will continue the work started as a single case study with Dr. John Aggleton (University of Durham), exploring further this patient's deficit in expression processing. An issue of particular interest concerns whether processing of expressions is as impaired for voices as for faces; i.e. whether there is an impairment of some form of supramodal expression mechanism rather than a mechanism specific to faces. Received wisdom in the neuropsychological literature is that deficits affecting the recognition of facial and vocal expressions are dissociable, but the relevant studies are sparse and unconvincing as to the level at which such fractionation occurs. It is known that visuo-verbal fusions are important in speech perception (Campbell, 1992), which gives grounds for speculating that an equivalent phenomenon might operate in the perception of emotion, for which some (but not all) of the same constraints apply.

Additional contacts with other researchers who have studied cases of bilateral amygdalotomy should also lead to the testing of further patients with the same tasks.

A2. Face Processing Impairments after Frontal Lobe Lesions: Although it is known that regions of posterior cortex involved in face perception are linked to particular areas in the frontal lobes (Wilson, ó Scalaidhe & Goldman-Rakic, 1993), and social and emotional changes are commonly reported after frontal lobe damage, there have only been patchy and unsystematic investigations of any corresponding face processing impairments. A more systematic study would show whether there is significant frontal lobe involvement in different aspects of face (and voice) processing, and could lead to the identification of individual patients with theoretically important deficits in expression perception. For this purpose, patients with lesions of different frontal regions will be compared on recognition of familiar faces, recognition of facial expressions, recognition memory for faces, and unfamiliar face matching, using updated versions of tasks from previous work (Young et al., 1993a). If possible, lesions centred on ventromedial and dorsolateral frontal cortex will be contrasted. Equivalent tests of voice processing will be developed to allow investigation of whether any impairments found affect only faces, or are multimodal in nature. This will also provide an important point of comparison to the case studies of amygdalotomy (A1).

A3. Development of Test Materials: A lot of the work needed for these proposed neuropsychological studies involves preparing and assembling appropriate materials. The Ekman and Friesen (1976) pictures of facial affect are readily available and have formed the basis of tests used previously (Young et al., 1993a), and some of the necessary tests of vocal emotion processing have also been prepared (6.32). For both visual and auditory presentation, however, a more thorough approach is needed. For example, it is necessary to have tasks involving moving facial stimuli. Although the emotions portrayed in the Ekman and Friesen (1976) face photographs are accurately recognised by normal observers, it remains the case that in everyday life emotions are often seen as fixed action patterns of facial movement. There is evidence that information about movement is carried by a separate neural channel to information about static form, and this has been found important in work on the recognition of expression and identity both in normal people (Bruce & Valentine, 1988) and after brain injury (Humphreys, Donnelly & Riddoch, 1993). In addition, stimuli are needed to test the comprehension of emotional terms. This is usually done very informally, but for multimodal deficits especially it will be important to rule out (or rule in) the possibility that failure to recognise emotions reflects failure properly to comprehend what it means to be angry, sad, afraid etc.

Tasks are also needed to look more systematically at the processing of emotional and conventional facial and vocal gestures. Goldblum (1980) reported a double dissociation between deficits in recognising emotional facial expressions and conventional facial gestures used in social interaction. Although this finding is consistent with other evidence on the dissociation of lipreading and expression perception (Campbell, 1992), it has not been followed up. In addition, further tests are needed to explore the relation between facial expression processing and recognition of other visual signals that convey emotion, such as body posture.

B. Experiments with Normal Subjects *(Young)*

As in previous work on face recognition, a fruitful approach should be to integrate neuropsychological and experimental approaches wherever possible. In tandem with the neuropsychological work on expression perception, therefore, experimental studies of priming and related effects on the recognition of facial expressions will be conducted.

B1. Short- vs. Long-Term Priming of Expression Recognition: An intriguing finding has been that there is no long-term benefit (across intervals of around 20 minutes) of having previously classified the expression shown in a face photograph on performing the task again (i.e., there is no subsequent benefit on making the same classification to the same photograph). Put another way, there do not seem to be long-term repetition priming effects in the processing of a particular face's expression (Ellis, Young & Flude, 1990). The expression recognition system may be set up this way because of the need to monitor constant but often subtle changes in the moods of other people; for this purpose, analysing someone's current mood by biasing your judgement toward their mood of 20 minutes ago might not be an optimal way to proceed. However, it seems likely that other forms of priming effect might occur, either short-term effects on analysing the expression on a particular person's face or, perhaps more importantly, a short-term or long-term bias toward the perception of particular emotions on any face. A finding of the latter type would, of course, fit neatly into other work at APU on cognition and emotion (6.1).

Investigations of short-term benefits in processing expressions will therefore be carried out, in which we will investigate the influence of having previously classified expression A in person X's face on subsequent recognition of the same emotion on the same face, the same emotion on a different face, or a different emotion on the same face.

B2. Within and Cross-Domain Priming of Expression Recognition: A technique which has proved very useful in experiments on the recognition of identity is to contrast priming effects which only arise within the same domain (e.g., from face to face) with effects which can cross stimulus domains (e.g., from face to name). This can be adapted to the investigation of the processing of emotion by comparing priming effects from facial expressions onto the recognition of expression labels. Since the structure of within and cross-domain priming effects on the recognition of identity has been both documented and simulated (Burton & Bruce, 1993), it should be possible to make relatively rapid progress in understanding priming effects on the recognition of expressions.

C. Delusional Misidentification***(Young, de Pauw, Ellis, Szulecka)***

A separate focus of interest is in investigations of face processing impairments and other cognitive components of delusions and delusional misidentification.

C1. Relation between Capgras and Cotard Delusions: Face processing impairments are often found in cases of delusional misidentification (Young, Ellis, Szulecka & de Pauw, 1990; Young et al., 1993b). This observation has led to the idea that the Capgras delusion (in which relatives are claimed to have been replaced by impostors) reflects an interaction of impairments. One set of contributory factors involves anomalous perceptual experience, and especially impaired emotional reactions to faces and other familiar visual stimuli (Ellis & Young, 1990); the second set of factors lead to an incorrect interpretation of this, creating a misattribution which is particularly likely in people who are in a highly suspicious mood (Young et al., 1993b). This general approach can also encompass other forms of delusion.

Delusional misidentification may thus relate closely to other forms of delusion that would otherwise appear highly distinct, since the same anomalous experiences can be misinterpreted in different ways. This insight can be used to explore a potential link to the Cotard delusion, in which patients are convinced that they are dead. In such cases, the patients are nearly always severely depressed, but it is known from other studies that people who are depressed will be more likely to misattribute loss of affective responses to themselves instead of others. This may explain similarities between the brain lesions, neuropsychological test profiles, and subjective reports of people experiencing the Cotard delusion and cases of Capgras delusion (6.56). The hypothesis is that patients who are suspicious will experience the Capgras delusion because they attribute their loss of affective reactions to others; those who are depressed but not suspicious will be more likely to experience the Cotard delusion because they correctly attribute the loss to themselves, but exaggerate its effects (Wright et al., 1993).

The usefulness of this hypothesis will be further investigated by examining other cognitive components of such delusions. For example, recent work being developed by postgraduate student Kate Leafhead has shown the usefulness of the notion that delusions are in part maintained by similar factors to those involved in anxiety states. Using the emotional Stroop paradigm (Bentall & Kaney, 1989; Williams & Broadbent, 1986), it can be shown that items which relate to the patient's delusions readily engage their attention.

C2. Domain-Specific vs. General Impairments in Delusional Misidentification: A key feature of Ellis and Young 's (1990) account of delusional misidentification is that it suggests a basis in malfunction of the visual system. However, other accounts, such as Cutting's (1991) categorisation failure hypothesis, predict a more central breakdown of semantic representations. For hypotheses which treat reduplication as a malfunction of the visual recognition system, specifically visual deficits are to be expected, whereas on the categorisation failure hypothesis, the problem should arise regardless of input domain. Such predictions should be readily testable, and can be investigated with the tasks being developed for neuropsychological studies (A3).

PUBLICATIONS (Excluding work done prior to arrival at APU)

Authored Books

6.1. TEASDALE, J.D. & BARNARD, P.J. (1993). Affect, Cognition and Change. Hove: Lawrence Erlbaum Associates.

6.2. WILLIAMS, J.M.G. (1992). The Psychological Treatment of Depression (second edition). London: Routledge.

Edited Books

6.3.* BADDELEY, A.D., WILSON, B.A. & WATTS, F.N. (Eds.) (in press). Handbook of Memory Disorders. Chichester: John Wiley & Sons.

6.4. Parry, G. & WATTS, F.N. (Eds.). (in press). Behavioural and Mental Health Research: A Handbook of Skills and Methods, second edition. Hove, Sussex: Lawrence Erlbaum.

6.5. WATTS, F.N. (Ed.). (1993). Neuropsychological perspectives on emotion. Special issue of Cognition and Emotion. Hove: Sussex: Lawrence Erlbaum Associates.

Refereed Articles

6.6. BARNARD, P.J. & TEASDALE, J.D. (1991) (equal authorship). Interacting cognitive subsystems: A systemic approach to cognitive-affective interaction and change. Cognition and Emotion, 5, 1-39.

6.7. Carr, S.J., TEASDALE, J.D. & Broadbent, D.E. (1991). Effects of induced elated and depressed mood on self-focused attention. British Journal of Clinical Psychology, 31, 273-275.

6.8. Constans, J.I. & MATHEWS, A.M. (1993). Mood and the subjective risk of future events. Cognition and Emotion, 7, 545-560.

6.9. COYLE, K. & WATTS, F.N. (1991). The factorial structure of sleep dissatisfaction. Behaviour Research and Therapy, 29, 513-520.

6.10. Dalgleish, T. & WATTS, F.N. (1990). Biases of attention and memory in disorders of anxiety and depression. Clinical Psychology Review, 10, 589-604.

6.11. DRITSCHEL, B. & TEASDALE, J.D. (1991). Individual differences in affect-related cognitive operations elicited by experimental stimuli. British Journal of Clinical Psychology, 30, 151-160.

6.12. EAST, M.P. & WATTS, F.N. (in press). The inner articulation rate of stutterers. European Journal of Disorders of Communication.

6.13. EAST, M.P. & WATTS, F.N. (in press). Worry and the suppression of imagery. Behaviour Research and

Therapy.
6.14. Evans, J.M., WILLIAMS, J.M.G., O'Loughlin, S. & Howells, K. (1992). Autobiographical memory and problem-solving strategies of patients who parasuicide. Psychological Medicine, 22, 399-405.
6.15. Jack, R.L. & WILLIAMS, J.M.G. (1991). The role of attribution in self-poisoning. British Journal of Clinical Psychology, 30, 25-35.
6.16. Jack, R.L. & WILLIAMS, J.M.G. (in press). Attribution and intervention in self-poisoning. British Journal of Medical Psychology.
6.17. LEVEY, A.B., Aldaz, J.A., WATTS, F.N. & COYLE, K. (1991). Articulatory suppression and the treatment of insomnia. Behaviour Research and Therapy, 29, 85-89.
6.18. LEVEY, A.B. & Martin, I. (1990). Evaluative conditioning: Overview and further options. Cognition and Emotion, 4, 31-37.
6.19. LEVEY, A.,B. & Martin, I. (1991). Psychophysiology and the inner world. Journal of Psychophysiology, 5, 1-3.
6.20. MACLEOD, A.K., Rose, G.S. & WILLIAMS, J.M.G. (in press). Components of hopelessness about the future in parasuicide. Cognitive Therapy and Research.
6.21. MACLEOD, A. & WILLIAMS, J.M.G. (1990). Overgeneralization: An important but non-homogeneous construct. British Journal of Clinical Psychology, 29, 443-444.
6.22. MACLEOD, A.K. & WILLIAMS, J.M.G. (1991). Moderate levels of chronic mood disturbance are associated with increased cognitive complexity about the self. British Journal of Medical Psychology, 64, 179-188.
6.23. MACLEOD, A.K., WILLIAMS, J.M.G. & Bekerian, D.A. (1991). Worry is reasonable: The role of explanations in pessimism about future personal events. Journal of Abnormal Psychology, 100, 478-486.
6.24. MACLEOD, A.K., WILLIAMS, J.M.G. & Linehan, M.M. (1992). New developments in the understanding and treatment of suicidal behaviour. Behavioural Psychotherapy, 20, 193 - 218.
6.25. Markar, H.R., WILLIAMS, J.M.G., Wells, J. & Gordon, L. (1991). Occurrence of schizotypal and borderline symptoms in parasuicide patients: Comparison between subjective and objective indices. Psychological Medicine, 21, 385-392.
6.26. Marx, E.M., WILLIAMS, J.M.G. & Claridge, G.C. (1992). Depression and social problem solving. Journal of Abnormal Psychology, 101, 78-86.
6.27. MATHEWS, A. & MILROY, R. (in press). Effects of priming and suppression of worry. Behaviour Research and Therapy.
6.28. MATHEWS, A. & MILROY, R. (in press). Processing of emotional meaning of anxiety. Cognition and Emotion.
6.29. MATHEWS, A., Mogg, K., Kentish, J. & Eysenck, M. (in press). Effect of psychological treatment on cognitive bias in generalized anxiety disorder. Behaviour Research and Therapy.
6.30. MATHEWS, A. & Sebastian, S. (1993). Suppression of emotional Stroop effects by fear-arousal. Cognition and Emotion, 7, 517-530.
6.31. Mogg, K., Bradley, B., Williams, R. & MATHEWS, A. (1993). Subliminal processing of emotional information in anxiety and depression. Journal of Abnormal Psychology, 102, 304-311.

6.32. Reid, I., YOUNG, A.W. & Hellawell, D.J. (1993). Voice recognition impairment in a blind Capgras patient. Behavioural Neurology, 6, 225-228.
6.33. Roberts, A. & WILLIAMS, J.M.G. (1992). Effect of olfactory stimuli on mood: A case for aromatherapy? British Journal of Medical Psychology, 65, 197 199.
6.34. TEASDALE, J.D. (1993). Emotion and two kinds of meaning: Cognitive therapy and applied cognitive science. Behaviour Research and Therapy, 31, 339-354.
6.35. TEASDALE, J.D., DRITSCHEL, B.H., TAYLOR, M.J., Proctor, L., LLOYD, C.A., NIMMO-SMITH, I. & BADDELEY, A. D. (in press). Stimulus-independent thought depends on central executive resources. Memory and Cognition.
6.36. TEASDALE, J.D., Proctor, L., LLOYD, C.A. & BADDELEY, A.D. (1993). Working memory and stimulus-independent thought: Effects of memory load and presentation rate. European Journal of Clinical Psychology, 5, 417-433.
6.37. TEASDALE, J.D., Segal, Z.V. & WILLIAMS, J.M.G. (in press). How does cognitive therapy prevent depressive relapse and why should attentional control (mindfulness) training help? An information-processing analysis. Behavioural Research and Therapy.
6.38. TEASDALE, J.D., TAYLOR, M.J., Cooper, Z., Hayhurst, H. & Paykel, E.S. (in press). Depressive thinking: Shifts in construct accessibility or in schematic mental models? Journal of Abnormal Psychology.
6.39. WATTS, F.N. (1990). Aversion to personal body hair: A case study in the integration of behavioural and interpretative methods. British Journal of Medical Psychology, 63, 335-340.
6.40. WATTS, F.N. (1992). Applications of current cognitive theories of the emotions to the conceptualization of emotional disorders. British Journal of Clinical Psychology, 31, 153-167.
6.41. WATTS, F.N. (in press). An information processing approach to compulsive checking. Clinical Psychology and Psychotherapy.
6.42. WATTS, F.N., Apps, J. & EAST, M.P. (1993). Personality change produced by expedition stress: A controlled study. Personality and Individual Differences, 15, 603-605.
6.43. WATTS, F.N., Cohen, J. & TOPLIS, R. (in press). Personality and coping strategies on a stressful expedition. Personality and Individual Differences.
6.44. WATTS, F.N. & COYLE, K. (1992). Recall bias for stimulus and response: Anxiety words in spider phobics. Anxiety Research, 4, 315-323.
6.45. WATTS, F.N. & COYLE, K. (1993). Phobics show poor recall of anxiety words. British Journal of Medical Psychology, 66, 373-382.
6.46. WATTS, F.N., COYLE, K. & EAST, M.P. (1994). The contribution of worry to insomnia. British Journal of Clinical Psychology, 33, 211-220.
6.47. WATTS, F.N. & Dalgleish, T. (1991). Memory for phobia-related words in spider phobics. Cognition and Emotion, 5, 313-329.
6.48. WATTS, F.N., Dalgleish, T., BOURKE, P. & Healy, D. (1990). Memory deficit in clinical depression: Processing resources and the structure of materials. Psychological Medicine, 20, 345-349.
6.49. WATTS, F.N., EAST, M.P. & COYLE, K. (in press). Insomniacs' perceived control over sleep. Psychology

and Health.
6.50. WATTS, F.N., Webster, S.M., Morley, C.J. & Cohen, J. (1992). Expedition stress and personality change. British Journal of Psychology, 83, 337-341.
6.51. WATTS, F.N., Webster, S.M., Morley, C.J. & Cohen, J. (1993). Cognitive strategies in coping with expedition stress. European Journal of Personality, 7, 255-266.
6.52. WILLIAMS, J.M.G., Healy, D., TEASDALE, J., White, W. & Paykel, E.S. (1990). Dysfunctional attitudes and vulnerability to persistent depression. Psychological Medicine, 20, 375-381.
6.53. WILLIAMS, J.M.G. & Markar, H.R. (1991). Money hidden and rediscovered in subsequent manic phases: A case of action dependent on mood state? British Journal of Psychiatry, 159, 579-581.
6.54. YOUNG, A.W., Flude, B.M., Hellawell, D.J. & Ellis, A.W. (in press). The nature of semantic priming effects in the recognition of familiar people. British Journal of Psychology.
6.55. YOUNG, A.W., Humphreys, G., Riddoch, J., Hellawell, D, & de Haan, E. (1994). Recognition impairments and face imagery. Neuropsychologia, 32, 693-702.
6.56. YOUNG, A.W., Robertson, I.H., Hellawell, D.J., de Pauw, K.W. and Pentland, B. (1992). Cotard delusion after head injury. Psychological Medicine, 22, 799-804.
Submitted
6.57. LLOYD, C.A. & TEASDALE, J.D. Context-dependent availability of intentions. (Manuscript submitted to Motivation and Emotion)
6.58. Segal, Z.V., WILLIAMS, J.M.G., TEASDALE, J.D. & Gemar, M. A cognitive science perspective on kindling and episode sensitization in recurrent affective disorder. (Manuscript submitted to British Journal of Psychiatry)
6.59. TEASDALE, J.D. & DRITSCHEL, B.H. Mood congruous memory: Self-relevance is not sufficient. (Manuscript submitted to British Journal of Clinical Psychology)
6.60. TEASDALE, J.D. & HUTTON, J.M. (a) Maintaining an attentional focus reduces depressive thinking. (Manuscript submitted to British Journal of Clinical Psychology)
6.61. TEASDALE, J.D. & HUTTON, J.M. (b) Sociotropy and response to brief social isolation. (Manuscript submitted to British Journal of Clinical Psychology)
Invited Chapters and Commentaries
6.62. Eves, F., Blizard, R., LEVEY, A. & Martin, I. (1990). Cardiac reactions to passive stimulation in twins. In P.J.D. Drenth, J.A. Sergeant & R.J. Takens (Eds.), European Perspectives in Psychology, Vol. 2 (pp. 443-457). Chichester: John Wiley & Sons.
6.63. MACLEOD, A. (in press). Judgemental biases in anxiety. In J.P. Caverni, J.-M. Fabre & M. Gonzalez (Eds.), Cognitive Biases. North-Holland: Elsevier.
6.64. MACLEOD, A.K. & WILLIAMS, J.M.G. (1992). The cognitive psychology of parasuicidal behaviour. In P. Crept, G. Ferrari, S. Platt & M. Bellini (Eds.), Suicidal Behaviour in Europe: Recent Research Findings. Rome: John Libbey,
6.65. MATHEWS, A. (1993). Anxiety and the processing of emotional information. In L.J. Chapman, J.P. Chapman & D.C. Fowles (Eds.), Progress in Experimental Personality and Psychopathology Research, Vol. 16 (pp. 254-280). New York: Springer Publishing Company.

6.66. MATHEWS, A. & MacLeod, C. (1994). Cognitive approaches to emotion and emotional disorders. Annual Review of Psychology, 45, 25-50.
6.67. TEASDALE, J.D. (1991). Cognitive vulnerability to persistent depression. In P. Slade (Ed.), The Psychology of Depression: Current Issues in Research and Practice (pp. 42-51). Deparment of Psychology, University of Sheffield.
6.68. TEASDALE, J.D. (1992). Cognitive models of depression: The state of the notion. Psychological Inquiry, 3, 269-271.
6.69. TEASDALE, J.D. (1993). Selective effects of emotion on information processing. In A.D. Baddeley & L. Weiskrantz (Eds.), Attention: Selection, Awareness and Control: A Tribute to Donald Broadbent (pp. 374-389). Oxford: Clarendon Press.
6.70. TEASDALE, J.D. (in press). A cognitive-behavioral perspective on assessment in the investigation of recurrent mood and anxiety disorders. In S. Hollon & B.E. Wolfe (Eds.), Methodological Issues in the Investigation of Treatment of Chronic and/or Recurrent Anxiety and Mood Disorders. Washington, D.C.: American Psychological Association Books.
6.71. TEASDALE, J.D. (in press). Clinically relevant theory: Integrating clinical insight with cognitive science. In P. Salkovskis & D.M. Clark (Eds.), Frontiers of Cognitive Therapy. New York: Guilford Press.
6.72. WATTS, F.N. (1993). Problems of memory and concentration. In C.G. Costello (Ed.), Symptoms of Depression (pp. 113-140). New York: John Wiley & Sons.
6.73. WATTS, F.N. (1993). The current state of jealousy: A review of recent books. Cognition and Emotion, 7, 217-223.
6.74. WATTS, F.N. (in press). Depression and anxiety. In A.D. Baddeley, B. Wilson & F.N. Watts (Eds.), Handbook of Memory Disorders. Chichester: John Wiley.
6.75. WATTS, F.N. (in press). Health and illness. In C. Fraser & G. Duveen (Eds.), Social Psychology. Cambridge: Polity Press.
6.76. WILLIAMS, J.M.G. (1990). When stress becomes depression. In J.A. Graham & L. Wallace (Eds.), The Complete Mind and Body Book (pp. 44-45). New York: Simon and Schuster.
6.77. WILLIAMS, J.M.G. (1992). Autobiographical memory in emotional disorder. In S.A. Christianson (Ed.), Handbook of Emotion and Memory (pp. 451-477). New York: Lawrence Erlbaum Associates.
6.78. WILLIAMS, J.M.G. & DRITSCHEL, B. (1992). Categoric and extended autobiographical memories. In M.A. Conway, D.C. Rubin, H. Spinnler & W. Wagenaar (Eds.), Theoretical Perspectives on Autobiographical Memory (pp. 391-409). Dordrecht: Kluwer Academic Publishers.
6.79. WILLIAMS, J.M.G. & MACLEOD, A.K (1990). Cognitive processes in parasuicide: Memory, hopelessness and schizotypal phenomena. In G. Ferrari, M. Bellini & P. Crepet (Eds.), Suicidal Behaviour and Risk Factors. Bologna: Monduzzi Editore.

Conference Proceedings

6.80. MATHEWS, A. (1993). Biases in processing emotional information. The Psychologist, 6, 493-499.

6.81. MATHEWS, A. (in press). Selective memory for emotional information. In D. Herrmann, M. Johnson, C.

McEvoy, C. Hertzog & P. Hertel (Eds.), Proceedings of the Third Practical Aspects of Memory Conference. Lawrence Erlbaum Associates.

6.82. WATTS, F.N. (1990). Emotion and Thinking. In K.J. Gilhooly, M.T.G. Keane, R.H. Logie & G. Erdos (Eds.), Lines of Thinking: Reflections on the Psychology of Thought, Vol. 2 (pp.117-119). Chichester: John Wiley & Sons Ltd.

6.83. WATTS, F.N. (1990). The cohesiveness of phobic concepts. In K. Gilhooly, M. Keane, R. Logie & G. Erdos (Eds.), Lines of Thinking. Reflections on the Psychology of Thought, Vol. 2 (pp.145-155). Chichester: John Wiley.

6.84. WATTS, F.N. (Ed.). (1990). The Undergraduate Curriculum in Psychology. The British Psychological Society, Vol. 9. (Proceedings of a symposium held at the London Conference of the British Psychological Society on 20 December 1988).

6.85. WATTS, F.N. (1992). Is psychology falling apart? The Psychologist, 5, 489-494.

Technical Reports and Theses

6.86. LLOYD, C.A. (1993). Empirical investigations of self-regulatory models of behaviour and their implications for clinical depression. Unpublished PhD Thesis, University of Cambridge.

6.87. Segal, Z.V., WILLIAMS, J.M.G. & TEASDALE, J.D. (1994). Cognitive Behaviour Therapy - Maintenance Treatment: Therapist Manual for Group Treatment.

Dissemination

6.88. Good, D.A. & WATTS, F.N. (in press). Qualitative research. In G. Parry & F.N. Watts (Eds.), Behavioural and Mental Health Research: A Handbook of Skills and Methods, second edition. Hove, Sussex: Lawrence Erlbaum.

6.89. Lavender, A. & WATTS, F.N. (in press). Rehabilitation: Assessment. In S. Lindsay & G. Powell (Eds.), A Handbook of Clinical Adult Psychology. London: Routledge.

6.90. Lavender, A. & WATTS, F.N. (in press). Rehabilitation: Intervention. In S. Lindsay & G. Powell (Eds.), A Handbook of Clinical Adult Psychology. London: Routledge.

6.91. WATTS, F.N. (1993). The role of research. In G. Powell, R. Young & S. Frosh (Eds.), Curriculum in Clinical Psychology (pp. 32-35). Leicester: British Psychological Society.

6.92. WATTS, F.N. (in press). Experimental abnormal psychology. In G. Parry & F.N. Watts (Eds.), Behavioural and Mental Health Research: A Handbook of Skills and Methods, second edition. Hove, Sussex: Lawrence Erlbaum.

REFERENCES TO OTHER WORK

BARNARD, P. (1985). Interacting cognitive subsystems: A psycholinguistic approach to short-term memory. In A. Ellis (Ed.), Progress in the Psychology of Language, Vol. 2 (pp. 197-258). London: Lawrence Erlbaum Associates.

Bentall, R.P. & Kaney, S. (1989). Content specific information processing and persecutory delusions: an investigation using the emotional Stroop test. British Journal of Medical Psychology, 62, 355-364.

Beck, A.T. (1976). Cognitive Therapy and the Emotional Disorders. New York: International Universities Press.

Bower, G.H. (1981). Mood and memory. American Psychologist, 36, 129-148.

Brittlebank, A., Scott, J., Ferrier, N. & WILLIAMS, J.M.G. (1993). Autobiographical memory in depression: State or trait marker? British Journal of Psychiatry, 162, 118-121.
Bruce, V. & Valentine, T. (1988). When a nod's as good as a wink. The role of dynamic information in facial recognition. In M.M. Gruneberg, P.E. Morris & R.N. Sykes (Eds.), Practical Aspects of Memory: Current Research and Issues. Volume 1: Memory in Everyday Life (pp. 169-174). Chichester: Wiley.
Bruce, V. & YOUNG, A. (1986). Understanding face recognition. British Journal of Psychology, 77, 305-327.
Burton, A.M. & Bruce, V. (1993). Naming faces and naming names: exploring an interactive activation model of person recognition. Memory, 1, 457-480.
Campbell, R. (1992). The neuropsychology of lipreading. Philosophical Transactions of the Royal Society, B335, 39-45.
Cutting, J. (1991). Delusional misidentification and the role of the right hemisphere in the appreciation of identity. British Journal of Psychiatry, 159, 70-75.
Ekman, P. & Friesen, W.V. (1976). Pictures of Facial Affect. Palo Alto, California: Consulting Psychologists Press.
Ellis, A.W., YOUNG, A.W. & Flude, B.M. (1990). Repetition priming and face processing: priming occurs within the system that responds to the identity of a face. Quarterly Journal of Experimental Psychology, 42A, 495-512.
Ellis, H.D. & YOUNG, A.W. (1990). Accounting for delusional misidentifications. British Journal of Psychiatry, 157, 239-248.
Etcoff, N.L. & Magee, J.J. (1992). Categorical perception of facial expressions. Cognition, 44, 227-240.
Foa, E.B. & Riggs, D.S. (1993). Post-traumatic stress disorder in rape victims. American Psychiatric Press Review of Psychiatry, 12.
Goldblum, M.C. (1980). La reconnaissance des expressions faciales émotionnelles et conventionnelles au cours des lésions corticales. Revue Neurologique, 136, 711-719.
Healy, D. & WILLIAMS, J.M.G. (1989). Mood, misattribution and mania: an interaction of biological and psychological factors in the pathogenesis of mania. Psychiatric Developments, 1, 49-70.
Higgins, E.T. (1987). Self-discrepancy: A theory relating self and affect. Psychological Review, 94, 319-340.
Humphreys, G.W., Donnelly, N. & Riddoch, M.J. (1993). Expression is computed separately from facial identity, and it is computed separately for moving and static faces: Neuropsychological evidence. Neuropsychologia, 31, 173-181.
Kabat-Zinn, J. et al. (1992). Effectiveness of a meditation-based stress reduction program in the treatment of anxiety disorders. American Journal of Psychiatry, 149, 936-943.
Nass, C., Steuer, J. & Tauber, E.R. (1994). Computers are social actors. In B. Addison, S. Dumais & J. Olson (Eds.), CHI '94: Human Factors in Computing Systems (pp. 72-77). New York: ACM
Nolen-Hoeksema, S., Morrow, J. & Fredrickson, B.L. (1993). Response styles and the duration of episodes of depressed mood. Journal of Abnormal Psychology, 102, 20-28.
Norman, D.A. & SHALLICE, T. (1980). Attention to Action: Willed and Automatic Control of Behavior. Center for Human Information Processing , Technical Report No. 99. (Reprinted in revised form in R.J. Davidson, G.E.

Schwartz & D. Shapiro (Eds.), Consciousness and Self-Regulation, Vol. 4 (pp. 1-18). New York: Plenum Press, 1986).

Pyszczynski, T. & Greenberg, J. (1987). Self-regulatory perseveration and the depressive self-focusing style: A self-awareness theory of reactive depression. Psychological Bulletin, 102, 122-138.

Schlesinger, I.M. (1992). The experiencer as agent. Journal of Memory and Language, 31, 315-332.

Scott, J., WILLIAMS, J.M.G. & Beck, A.T. (Eds.) (1989). Cognitive Therapy in Clinical Practice. London: Routledge.

Walker, J.H., Sproull, L. & Subramat, R. (1994). Using a human face in an interface. In B. Addison, S. Dumais & J. Olson (Eds.), CHI '94: Human Factors in Computing Systems (pp. 85-91). New York: ACM

WATTS, F.N., McKenna, F.P., Sharrock, R. & Trezise, L. (1986). Colour naming of phobia-related words. British Journal of Psychology, 77, 97-108.

Weissman, A. & Beck, A.T. (1978). The Dysfunctional Attitudes Scale. Paper presented at the annual meeting of the Association for the Advancement of Behavior Therapy, Chicago (November, 1978).

Wells, K.B. , Stewart, A., Hays, R.D., Rogers, W., Daniels, M., Berry, S., Greenfield, S. & Ware, J. (1989). The functioning and well being of depressed patients. Results from the medical outcome study. Journal of the American Medical Association, 262, 914-919.

WILLIAMS, J.M.G. (1989) Cognitive therapy for depression. In E.S. Paykel & K. Herbst. Depression: An Integrative Approach. Heinemann.

WILLIAMS, J.M.G. & Broadbent, K. (1986). Distraction by emotional stimuli: Use of a Stroop task with suicide attempters. British Journal of Clinical Psychology, 25, 101-110.

WILLIAMS, J.M.G. & Moorey, S. (1989). Cognitive therapy: The end of the beginning. In J. Scott, J.M.G. Williams, & A.T. Beck (Eds.), Cognitive Therapy in Clinical Practice. London: Routledge.

WILLIAMS, J.M.G., WATTS, F.N., MacLeod, C. & MATHEWS, A.M. (1988). Cognitive Psychology and Emotional Disorders. Chichester: John Wiley and Sons.

WILLIAMS, J.M.G. & Wells, J. (1989) Cognitive therapy with suicidal patients. In J. Scott, J.M.G. Williams, & A.T. Beck (Eds.), Cognitive Therapy in Clinical Practice. London: Routledge.

Wilson, F.A.W., ó Scalaidhe, S.P. & Goldman-Rakic, P.S. (1993). Dissociation of object and spatial processing domains in primate prefrontal cortex. Science, 260, 1955-1958.

Wright, S., YOUNG, A.W. & Hellawell, D.J. (1993). Sequential Cotard and Capgras delusions. British Journal of Clinical Psychology, 32, 345-349.

YOUNG, A.W. (1993). Covert recognition. In M. Farah & G. Ratcliff (Eds.), The Neuropsychology of Higher Vision: Collected Tutorial Essays. Hillsdale, New Jersey: Lawrence Erlbaum.

YOUNG, A.W. (1994). Conscious and nonconscious recognition of familiar faces. In C. Umiltà & M. Moscovitch (Eds.), Attention and Performance, XV: Conscious and Nonconscious Information Processing (pp. 153-178). Cambridge, Massachusetts: MIT Press/Bradford Books.

YOUNG, A.W. & de Haan, E.H.F. (1992). Face recognition and awareness after brain injury. In A.D. Milner & M.D. Rugg (Eds.), The Neuropsychology of Consciousness (pp. 69-90). London: Academic Press.

YOUNG, A.W., Ellis, H.D., Szulecka, T.K. & de Pauw, K.W. (1990). Face processing impairments and delusional

misidentification. Behavioural Neurology, 3, 153-168.
YOUNG, A.W., Newcombe, F., de Haan, E.H.F., Small, M. & Hay, D.C. (1993a). Face perception after brain injury: Selective impairments affecting identity and expression. Brain, 116, 941-959.
YOUNG, A.W., Reid, I., Wright, S. & Hellawell, D.J. (1993b). Face-processing impairments and the Capgras delusion. British Journal of Psychiatry, 162, 695-698.

Collaborations

Barnard

UK based

Murray - Psychiatry, Cambridge

Cooper - Psychology, Cambridge and Reading

Mathews

UK based

Bradley - Psychology, Cambridge

Mogg - Psychology, Cambridge

Outside UK

Borkovec - Pennsylvania State University

MacLeod - University of Western Australia

Teasdale

UK based

Paykel - Psychiatry, Cambridge

Scott - Psychiatry, Newcastle-upon-Tyne

Williams - Psychology, Bangor

Cooper - Psychiatry, Cambridge

Sheppard - Psychiatry, Cambridge

Kelvin - Psychiatry, Cambridge

Outside UK

Segal - Psychiatry, Toronto

A Young

UK based

Aggleton - Psychology, Durham

Calder - Psychology, Durham

Perrett - Psychology, St. Andrews

Ellis - Psychology, Cardiff

de Pauw, Szulecka - Psychiatry, Doncaster

Reid - Psychiatry, Aberdeen

Outside UK

Etcoff - Psychology, Massachusetts Institute of Technology