Progress Report
1985-1989

Summary of Research

Cognitive Neuropsychology

This is an area in which the Unit is particularly strong and active, suggesting that it should be covered in this overview. We have, however, opted to discuss the neuropsychological work of the Unit under the various topic areas to which it contributes, rather than as a separate topic. Anyone wishing to pick out this line of work should note the work on attention done by Burgess, Duncan, Marcel and Shallice, the research on language, reading and writing by Marcel, Marslen-Wilson, Patterson and Shallice, and the research on memory by Baddeley,
Gathercole and Shallice. Neuropsychological research on motor skills has been carried out by Wann and Wing, and in the general area of vision by Marcel and by Wilkins.

Attention (Projects 57-59)

The study of attention has been a major theme of the Unit's work for many years, and it comprises three current project areas which form a good example of the points just discussed. Project 57 is concerned with visual selective attention, and is represented principally by the work of Duncan, who has developed and elaborated the theory that was first mentioned in the last Progress Report, and which is now about to appear as a major theoretical paper [13]. The model, developed in collaboration with Humphreys (Birmingham), has been extensively explored using the task of visual search, which has supported the importance of two concepts, namely a template reflecting potential targets, and the characteristic features of the range of non-targets. The model gives a good account of existing neuropsychological and neurophysiological data and Duncan will spend next year carrying out collaborative single-cell recording work on monkeys, with Desimone in NIH Washington, developing the neurophysiological aspects of the model. The possibility of linking neuropsychological and neurophysiological theory represents an exciting development in cognitive psychology, and one which I would expect to become more marked in future years.
A major focus of much of the Unit's work over the last five years has been on Project 58 which is concerned with executive processes in cognition. These are so central and ubiquitous in cognitive psychology that it is tempting to place very large amounts of the Unit's work in this category. For example, the concept of working memory which is concerned with the temporary storage and manipulation of information as part of more complex processing tasks, is clearly very much concerned with executive processes, and could equally well be categorised as research on attention as on memory.
The study of the process or processes responsible for the attentional control of action plays a central role in the Unit's work. Shallice has worked on this problem for a number of years, and his joint model with Norman represents one of the few available conceptualisations of the attentional control of action. This was incorporated by Baddeley into his general model of working memory. In the case of neuropsychological studies, Baddeley and Shallice and Duncan all share an interest in patients with frontal lobe damage, who appear to offer a possible clue to the operation of this system. Using such patients, Shallice and Baddeley have both observed an association between amnesia in frontal patients and confabulation, and both have drawn conclusions about the implications of this for the processes of normal retrieval.
Duncan's interest in the attentional control of action stems in part from his work on driving, leading him to an approach using dual-task performance, a route that has also been used by Baddeley in studying the role of working memory in complex skills such as chess playing and the acquisition of complex computer games. In future, Duncan and Baddeley plan to collaborate in using psychometric techniques to explore the relationship between the functioning of the controlling Central Executive component of working memory and older concepts of general intelligence. They plan to use individual difference measures and secondary task procedures, in a collaborative study with a U.S. Air Force group concerned with fundamental research into individual differences.
In addition to the above-mentioned work, Marcel's demonstrations of the role of intention (in projects 68.3 and 68.4) are clearly aspects of executive function. In the first case the nature of an intended action seems to determine parameters of spatial representation, in the second case the nature of an intention seems to determine accessibility and fluency of motor control.
Given the parallels and similarities that are emerging from work in this area, it must be tempting to ask why the four groups have not worked together more extensively. The answer is that they were initially working on quite separate projects, Shallice on frontal lobe patients, Duncan on driving, Baddeley on short-term memory and Marcel on perceptual-motor control, all with adequate theories that appeared to be working quite well. The fact that these somewhat independent theories are now converging on broadly common and compatible conclusions is a point in their favour. Cognitive psychology is at present simply not in a state where detailed agreement on theory is a sensible prerequisite of a research programme. I would suggest however that the APU provides good evidence that cognitive psychologists with broadly compatible assumptions can work in a fruitful and cumulative way.

Further evidence for this comes from Project 59 which is concerned with the analysis of the structure and functions of consciousness. This is clearly one of the most important but most difficult questions of psychology. Relevant work at the APU includes Marcel's demonstration that information can be available to a subject and can be used without the subject being consciously aware of that information. He has continued to explore this area empirically, using the phenomenon of blindsight, whereby patients with cortical blindness are able to make visual judgements about objects of which they report no phenomenological awareness. There has been a recent increase in the amount of activity concerned with the issues of consciousness, a development in which Marcel has played an important role. He plans in future to turn to the issue of awareness of bodily sensation, a topic that has been curiously neglected by psychologists, despite their considerable interest in the associated problem of pain.
The role of conscious awareness in short-term or working memory is also an important but under-explored topic; the work by Teasdale on intrusive stimulus-independent thoughts, and by Watts and Levey on the role of such thoughts in insomnia, indicate that this area can be tackled empirically by using the very simple expedient of asking subjects at irregular intervals just what they are thinking about. Such simple but potentially useful thought-reporting methods will be used to extend existing models to explore the role of conscious awareness in working memory.

Audition (Projects 60-61)

This is an area in which a single very successful integrated group is now establishing much closer links with other aspects of the Unit's work. During the past five years, the work on auditory warnings has continued to bear fruit, leading to a number of patents and British and International Standard specifications. Sets of auditory warnings have been delivered to the Civil Aviation Authority for civilian fixed-wing aircraft, and have been developed for three separate military helicopters, as well as being fitted in North Sea oilfield helicopters. Other applications include the development of an auditory warning system for hospitals (intensive care wards and operating theatres), and railway track-side crews.
Although this is an example of a very successful application of basic research in psychoacoustics, it also illustrates the potential danger of successful applied work, since our psychoacoustics section could spend its whole time developing alarms for the very many situations in which they are needed. Ideally, these projects would be taken on by industry; however our industrial partners typically do not have the necessary psychological expertise. An alternative is to delegate the running of the project to a junior scientist at the APU. In principle this is feasible, but unfortunately suitable psychoacousticians are few and far between, and once trained tend to leave for more lucrative jobs elsewhere.
Meanwhile Patterson has been actively developing a model of auditory sensation and extending it to the problem of speech recognition. This has led to his being the coordinator of a European funded ESPRIT Basic Research Action which involves collaboration between the APU and speech scientists from a range of disciplines and countries. Within the APU, the ESPRIT project will involve collaborative work on speech between a number of previously separate groups including that of Cutler and Norris on speech perception, Houghton and Shanks on connectionist modelling and Baddeley on phonological memory.

Language and Speech (Projects 62-64)

Although language consists of separable words, spoken language in fact comprises a virtually continuous stream of sound. This raises the problem of how to segment the incoming signal into separate words. Cutler and Norris in collaboration with Mehler and Segui in Paris have shown that this process differs between French, where the discrimination is based on syllabic units and English, which appears to rely on the tendency for English words to have their stress on the initial syllable.
Cutler and Norris propose to test a number of models of this process, which is of course very important for attempts to develop devices for automatic speech recognition. As mentioned earlier, this will involve the detailed development of connectionist models of speech recognition, as part of the ESPRIT BRA project.
The Unit has continued to be active in the study of reading and writing and their breakdown in dyslexia and dysgraphia. Detailed analysis of the reading deficit in patients who have become dyslexic following brain damage has been continued by Patterson, Marcel and Shallice. This again is an area that has been strongly influenced in recent years by the development of ambitious connectionist models of normal reading. Patterson has been collaborating with McClelland in Pittsburgh and Seidenberg in Montreal to develop such a model, her concern being particularly with the exploration of the extent to which "lesioning" such a model will produce errors that are analogous to those produced by certain types of dyslexic patient. A similar approach is being pursued by Shallice in collaboration with Hinton in Toronto. This work has so far proved extremely promising and will be actively pursued over the coming years. Other aspects of the Unit's programme in reading research involve (a) relationships between impaired reading and other language skills such as speech segmentation, (b) models for skilled and disordered reading in various orthographies and (c) plans for more sophisticated neurological localisation of components of the reading process via PET-scanning activation studies.

Learning and Memory (Projects 65-66)

This continues to be an active area, with the Unit involved in research on both working memory and long-term memory. One of the major developments in this area over the last five years has been the attempt to explore the real-world validity of one subsystem of working memory, the Articulatory or Phonological Loop, a system that is concerned with the phonological storage and rehearsal of verbal material. Earlier work was largely confined to laboratory studies, which have left open the question of whether the system is of any practical importance. However, recent studies by Baddeley in collaboration with Vallar and Papagno in Milan, and Wilson in Southampton involving neurological patients with short-term memory deficits suggest that the system is of real importance, both in understanding language, and in learning new phonological sequences, such as new words in one's native or a foreign language. Further research on normal children by Gathercole and Baddeley indicates that the capacity of this system has a major influence on the initial acquisition of vocabulary and is important for the early stages of reading. Future work aims to continue longitudinal studies to investigate further the ramifications of the system. We also plan to develop a more specific model of the phonological store, as part of the previously mentioned ESPRIT BRA speech project, using parallel distributed processing or connectionist techniques to implement models of memory storage and retrieval in ways that appear to be plausible both psychologically and physiologically.

One of the major features of recent years in long-term memory research has been the growth of interest in autobiographical memory, the capacity to recall incidents of one's earlier life. This area of memory research has until recently been curiously neglected, probably because of methodological problems in deriving quantitative measures. It is however of considerable practical importance in areas such as eyewitness testimony, and in assessments of the effects of case presentation features on the memory and decisions of juries, both areas that have been studied by Bekerian.

Clinical disturbance of autobiographical memory has also evoked considerable interest; this includes work by Shallice and by Baddeley on confabulation in frontal lobe patients mentioned earlier, and research by M. Williams on disturbances in the precision of autobiographical memory in patients who have attempted suicide. The observation of varying patterns of deficit in autobiographical memory in amnesic patients has led to the development of a clinical test of autobiographical memory by Baddeley in collaboration with Wilson in Southampton and Kopelman at Charing Cross. This is part of an ongoing programme concerned with the development of clinical memory tests which has so far produced a test of everyday memory in collaboration with Wilson and Cockburn of Rivermead Rehabilitation Centre in Oxford. We plan to standardise and publish clinical tests of verbal and visual long-term memory, semantic memory and of the various components of working memory.

Connectionist and other network models have also recently had a major impact on theories of learning and memory. Such parallel models appear to capture the characteristics of the processes of storage and retrieval much more naturally than does the more conventional computer analogy, in which information is stored perfectly in a range of discrete memory locations. We believe that the full exploitation of parallel network models for psychology will require a combination of the understanding of their strengths and weaknesses with a willingness to confront them with carefully collected empirical data. The

Unit has a strong experimental tradition, and is currently developing its skills in modelling. Houghton is actively exploring connectionist architectures for both long- and short-term learning, while Shanks is concerned with models of concept acquisition and decision. Norris is concentrating on the use of connectionist models in speech perception, a process that almost certainly involves a component of phonological storage. Finally, McLaren, who will be joining the Unit as part of his King's College Research Centre Fellowship, will be working on a connectionist model of spatial attention, probably in collaboration with Duncan.

Perceptual-motor Skills (Projects 67-68)

In the past, Wing has been concerned with developing a theoretical account of noise in the timing of movement. With his theoretical account of timing now widely accepted, Wing is currently evaluating its applicability to new tasks including the coordination of multiple effectors. Recently, in collaboration with Ulrich in Germany, he has started to extend the account of motor variability into the force domain.

Time and force are rather elemental aspects of voluntary movement. A more usual focus of attention in research into the control of action is position in space, or, in the case of skills such as writing or drawing, the trajectory of position changes as reflected in the trace left by the pen on paper. Wann and Nimmo-Smith have been investigating strategic constraints on the way such voluntary positioning movements are executed. Mechanical equipment such as a computer pen-plotter is often driven in a very jerky style. This contrasts strongly with the smooth changes in velocity typically observed in human handwriting and which has led people to suggest that movement trajectories are organised to minimise the rate of change of acceleration. APU research has challenged some common simplifying assumptions within this perspective. Reformulated equations of motion are supported by behavioural data but, more importantly, they suggest a way in which the motor system could be informed of the consequences of jerky movement. This therefore constitutes a model of

feedback that has implications for the refinement of control in motor development or rehabilitation of neurologically impaired patients. It is expected that this will develop into a useful theoretical basis for current research projects at the APU in motor skills training (even though, regretfully, these will proceed less rapidly with Wann's lectureship appointment to Edinburgh).

Although variability in output means that our movements are not perfectly accurate, the motor system appears to compensate for errors automatically so that our actions usually achieve a successful outcome. The coordination between opening and positioning of the hand when reaching for an object in the environment is an example that has been studied by Wing in collaboration with Fraser and Turton. If normal use of visual information to guide the hand toward the object is restricted, a compensatory increase in hand opening is observed that improves the chances of encompassing the object. Current research by Haggard seeks to assay the separability of these strategically coordinated elements by imposing additional demands at various phases of reaching. Comparison of the effects of cognitive interference by a secondary task and the effect of mechanical perturbation to movement seem particularly promising.

Thinking (Projects 69-70)

Johnson-Laird, Anderson and Byrne have been further testing the proposal that much thinking involves the setting up and manipulation of mental models. They have systematically compared this approach with an alternative view of thinking based on the operation of sets of logical rules, an approach that dominated the area prior to Johnson-Laird's theory. The work has been concerned with two criticisms, that the model is too vague to be specified, and that it is not demanded by the empirical evidence. Areas of thinking that have been considered include the comprehension of discourse, everyday informal inferences, and deductions based on prepositional reasoning, relational reasoning and quantification. In each case a formalisation of the proposed mental model has been developed and programmed, and empirical evidence has been collected. The evidence consistently favours the mental model approach and in a number of cases produces data that are very difficult to explain in terms of the rival rule-based hypothesis. This work will continue, but unfortunately not in Cambridge, since Johnson-Laird has accepted a Chair at Princeton University.

Until very recently, studies on animal learning and cognition have proceeded quite independently of equivalent work on human subjects. There are now welcome signs of the two areas beginning to come together, partly under the influence of the development of connectionist learning models, and partly as a result of the development of cognitive theories of conditioning in animals, which appear to have implications for human cognition. Within this latter category, Shanks has been testing models of the judgement of causality, and finding that an associative model based on principles of conditioning offers a better account of the data than one based on normative rules. Similarly, animal conditioning models have proved highly successful in accounting for the results of a categorisation task in which, for example, subjects have to decide on the basis of symptoms whether a hypothetical patient is suffering from one disease or another. The conditioning model has been simulated using a connectionist network; future work will study its capacity to cope with more complex categorisation tasks, including that of diagnosticians making decisions on the basis of actual disease patterns.

Human-Computer Interaction (Projects 71-72)

This is an area in which the Unit has worked for many years, starting at a time when it was virtually unexplored, and reaching a point now at which it is one of the most intensively studied areas of applied psychology. One of the difficulties in working in this area is that the technology changes so rapidly that particular systems become obsolete before they have been adequately studied. This means that much of the applied work in the area has to be based on rule-of-thumb techniques, which ideally should be based on earlier evidence. Since the user of such information is typically not a psychologist, a major problem is how the necessary information can be delivered, and it is this that has concerned both Barnard and Young in recent years. Both have chosen to use AI techniques, with Young and Green opting to develop a cognitive model of the user that allows the software designer to program in the system and task characteristics, while Barnard has developed an expert system in which the rules are based upon Interacting Cognitive Subsystems, his very ambitious model of cognition. Working with these ideas, Young and Barnard are currently collaborating on an ESPRIT Basic Research Action, aimed at bringing modelling techniques from cognitive and computer science closer to the practical needs of software designers.

We remain active in the related area of exploring the cognitive demands of technical communications. Wright has continued her detailed analysis of the representation of linguistic information, exploring the conflict that sometimes occurs between the linguistically graceful and the logically desirable. She continues to provide practical help for those concerned with designing forms, as well as other varieties of communication, for example via the maps and signs that attempt to guide the visitor around a large and complex hospital. Investigation of the problems people have in communicating technical information suggests that they are often insufficiently aware of the alternatives available, whether to use words or pictures, and whether to provide an enquirer with the quickest or the easiest way. The development of desktop publishing offers an increasing

range of potential resources for the communicator; if they are to be used effectively, we need a more detailed and sophisticated understanding of the problems facing both the communicator and the recipient of the information.

Transport System Users (Project 73)

Research on the behaviour of transport users has been a prominent feature of the Unit's work for many years, and continues to be an area of considerable activity. A previous project involving Brown, Duncan, Groeger and P. Williams, concerned with comparisons amongst novice drivers, normal experienced drivers and experts revealed, among other things, that the normal experienced drivers were poorer than either of the other two groups on certain components of driving such as mirror-checking. The tasks concerned seemed to have the characteristic that failure to perform them does not normally lead to immediate feedback, although in the long run failure can be extremely serious. This has clear implications for road safety.

Detailed analysis of the skill of driving suggests that it comprises many different and independent subskills, making prediction of success in trainees very difficult. Executive functions appear to be less important than might have seemed likely, a conclusion that is consistent with a small study of head-injured patients. This showed that even patients with clear evidence of executive dysfunction show little impairment in driving skills, and suggests that medical criteria for return to driving should be re-examined.

A series of new externally-funded projects involving Groeger, Brown, Chapman and Grande has just begun. One collaboration (with Paris and University College London) concerns estimating time to coincidence or collision. It attempts to model the decisions drivers make at junctions. This should provide assistance to traffic engineers devising countermeasures to the problems of risk-taking at junctions. A second related study is concerned more directly with perception of risk, using video tapes of specific situations, and requiring drivers to assess the danger and relate it to their driving behaviour (this is funded by a contract from General Accident PLC).

A third project, this time funded by the CEC DRIVE Research Initiative, is concerned with the role of feedback from driving instructors during the process of learning to drive. It will attempt to relate this to the type of accidents encountered subsequently, using this information to identify the type of instructional support that might be given to the learner by an "intelligent" vehicle. This project is carried out in collaboration with the Traffic Research

Centre at Groningen. Brown is due to retire in three years' time, and the future of this area is one that is of considerable concern. We would hope to continue to work in this area, provided we can recruit senior staff who are capable of blending the many practical problems this area offers with the prospect of genuine theoretical development.

Vision (Projects 74-76)

A major component of the Unit's work in this area was the development by Watt of a theory of human vision and visual attention that combines information from psychophysics, computer science and cognitive psychology and is expressed in a recent book [561]. Unfortunately, Watt has just left to take up a Personal Chair in Psychology and Computer Science at Stirling. We hope to replace him by a senior appointment in a similar area.

Meanwhile, Wilkins' work on visual discomfort and environmental design continues to be extremely productive. He has shown that the characteristic flicker and stripe patterns that trigger epileptic attacks in photosensitive patients are also a major source of complaints of eyestrain and headache in non-epileptic subjects. This has important practical implications for a wide range of environmental design issues, including fluorescent lighting, computer VDUs and even the design of typeface, where certain types can be shown to produce clear stripe effects, and accompanying complaints of eyestrain and headache. The potential environmental significance of this phenomenon is very substantial. At the same time, Wilkins and Neary have been exploring possible mechanisms, elaborating and testing a theory of eyestrain described in the last progress report.

In the meantime, Wilkins has been applying the visual techniques developed to provide clinical tests useful in the diagnosis of a range of diseases including multiple sclerosis, optic neuritis, diabetes and glaucoma. Future proposals involve the continued investigation of visual discomfort in the office environment, and ways in which it can be alleviated, together with a continuation of the investigation and modelling of the visual symptoms associated with headache and reading.

Psychophysiology (Projects 77-78)

Work by Wilkinson on sleep has involved continued analysis of data collected from earlier fieldwork on individual sleep disturbance, together with the development of measures of sleep on/offset, using both behavioural and physiological measures. Future work will develop portable sleep detectors for use in industrial and field situations. Wilkinson is due to retire in a year's time, an event that colleagues in North America and

Britain plan to mark by organising a meeting in Cambridge on sleep and performance.
Levey, who forms the second senior member of the psychophysiology section, is also due to retire, bringing to an end his very productive line of research on human classical conditioning, carried out in collaboration with Martin at the Institute of Psychiatry. Plans for the future of the psychophysiology section will be discussed below.

Emotion and Cognition (Projects 79-80)

The Unit has sought to develop links between experimental and clinical psychology in the belief that any adequate theory of cognition must be able to incorporate an understanding of the role of motives and emotions. Since it is difficult to manipulate emotions ethically within the laboratory, we felt that work on clinical patients could be potentially of great significance for understanding normal cognition. At our last progress report, we had established a group in this area, but the Board felt that it was still too soon to assess the success of our attempt to bridge the gap between clinical and cognitive psychology. We are now in a much stronger position, with an active and coherent group that is not only developing strong connections between these two areas of psychology but is also beginning to influence theory within each of them.
One indication of the extent to which research on cognition and emotion has become integrated into the work of the Unit is the fact that no fewer than eight cognitive psychologists who do not see emotion as their principal area of research, have been involved in research in cognition and emotion over the period since our last progress report. These include Baddeley, Barnard, Bekerian, Conway, Dritschel, Johnson-Laird, Levey and Wilkins. A second achievement of the group has been the publication by Williams and Watts in collaboration with Mathews and MacLeod (of St George's Hospital Medical School) of Cognitive Psychology and Emotional Disorders, a book that has been very favourably reviewed, and which we believe reflects the growing tendency for cognitive psychology and clinical psychology to interact fruitfully.
The work in this area falls into two sub-areas, the interaction of emotion and cognition (Project 79), and the analysis and treatment of emotional disorders (Project 80). Past work on cognition and emotion has included the communicative theory of emotions devised jointly by Johnson-Laird and Oatley of Glasgow. Bekerian and Conway have explored the structuring of emotional and conceptual knowledge in a way that links up with previously-described research on semantic and autobiographical memory, and with the work by Williams on autobiographical memory in attempted suicide patients.
Teasdale has been concerned with the role of mood congruent memory in maintaining negative mood states, and has gone on to study methods of controlling the flow of negative thoughts, which have been shown to help maintain the depressed mood state in patients. A series of experiments have used Baddeley's working memory model to explore methods of controlling such thoughts, demonstrating the importance of the Central Executive component rather than peripheral slave systems in the process. Future plans involve adapting Barnard's model of Interacting Cognitive Subsystems to explore further the control of negative thoughts, with a view to developing therapeutic methods for encouraging and maintaining more positive affect in such patients. Barnard plans to devote more time to this and rather less to human-computer interaction throughout the coming five years.
Work on the analysis and treatment of emotional disorders has concentrated on patients suffering from depression, and from phobias. Work by Watts on depression has demonstrated genuine memory deficits which are not simply due to subjects having a bias against responding freely, and has suggested that the problem occurs at least partly as a result of the reduced organisational activity indulged in by the subject. Depressed patients tend, for example, to fail to pick out the more important features of text, and are more likely to rely on simple rote rehearsal. On the other hand, use of imagery is unimpaired, and Watts has successfully applied these findings to the treatment of work problems in students. This particular line of research is regarded as complete.
Attempted suicide presents a major practical problem which at present has not yielded readily to treatment. Williams has investigated the autobiographical memory of patients in an attempt to elucidate the nature of the hopelessness that appears to be an important determinant of whether or not the patient will attempt suicide again. Williams' work suggests that although such patients can access autobiographical memories, they report memories that are excessively general, and appear to have great difficulty in producing detailed specific recollections. Subsequent work showed that a similar phenomenon occurs in other depressed patients, and furthermore indicated that the phenomenon is also present in ex-patients who have recovered from their suicidal crisis. He proposes to examine this phenomenon in more detail, in particular exploring the relationship between autobiographical memory, hopelessness and the control of action, exploring the extent to which autobiographical memories of the past can be related to the patient's prediction of what will happen in the future. In collaboration with Scott and Ferrier at Newcastle, Williams will be studying a group of depressed patients longitudinally, with a particular view to exploring whether the generic style of recall identified in depressives will predict dysfunctional attitudes and subsequent relapse.
A series of experiments on patients' memory for phobic objects (such as spiders) by Watts and collaborators

has shown a pattern of results with some similarities to the lack of specificity in autobiographical recall by depressives. Phobics tend to have both very poor recognition memory and rather undifferentiated cognitive representations of phobic stimuli. This lack of precision appears to be associated with poorer subsequent emotional habituation to the stimuli. It is as if, in both the autobiographical memories of suicide patients, and the perception of fear-inducing stimuli by phobics, the degree of associated anxiety can be reduced by avoiding detailed processing and hence "distancing" the stimulus. Unfortunately however, this distancing mechanism appears to make it harder for the patient subsequently to adapt and come to terms with the source of anxiety. This emphasis on impoverished stimulus processing differentiates Watts' approach from that of Lang who emphasises the importance of the response aspects of anxiety. Future work will explore this hypothesis further, attempting to improve phobic encoding by inducing positive mood, and by attentional instructions. If successful, this should not only improve subsequent recall, but also lead to better desensitization.

A related problem is that of dealing with emotional memories which may continue to cause acute distress in patients long after the occurrence of the event. Recent work suggests that these memories again tend to be preoccupied with the patient's emotional response, with little attention to the details of what occurred. It is suggested that this prevents effective emotional processing, and that better ways of working through emotional memories may be available. The work is closely related to that of Williams on generic autobiographical memory, and of Teasdale on intrusive thoughts and mood biasing.

Finally, a collaboration between Watts and Levey is investigating a cognitive treatment of sleep dissatisfaction. This work is conceptualised in a working memory framework, and uses articulatory suppression as a means of blocking verbal behaviour, while requiring suppression to occur at irregular intervals, a task that occupies but does not stimulate and overload the Central Executive component. Preliminary results appear to be encouraging, and a formal trial of the treatment is just beginning.

The Next Five Years

While we have attempted in the body of the Progress Report to indicate for each research area, the direction we plan to take, given the number of projects, it may be difficult for the reader to gain an overall feel for the broad research strategy of the Unit. The present section aims to fulfil that function.

In many ways the broad theme of the Unit's work has remained remarkably constant over its 45 years of life. We began with a strong commitment to theory, based on the concept developed by Craik of the model as a means of theorising, and using the electronic computer to model human cognition. We are still strongly committed to theory, still use an information-processing metaphor, and tend to rely quite heavily on computer modelling. In our last Progress Report we made a plea for better equipment, and I am delighted to say that the Council responded very positively.

Much of the Unit's theoretical work continues to be concerned with the detailed modelling of specific cognitive processes. However, the development of the techniques of Artificial Intelligence has led to the creating of unified theories of cognitive processing. Within the Unit three broad approaches to achieving such integration are represented. One approach is based on connectionist architectures (Parallel Distributed Processes). Such models emphasise the interaction among large numbers of inter-connected subunits. Another approach to parallel processing has been achieved by an architecture comprising a number of dedicated processing modules. In this approach, which is typified by the Interacting Cognitive Subsystems model, structural complexity is traded against processing simplicity. This work provides a link with the third approach which is based on models using a Production Systems architecture, with cognition being modelled as the operation of rules that have been learned. The next five years will see clarification of the scope and power of these theoretical approaches. My own view is that the viability of these theories depends upon the level of the cognitive functions being modelled, with some tasks such as pattern recognition being much more readily captured by connectionist models, while other tasks such as planning and problem solving may be more amenable to a Production System approach. It is likely that any powerful account of complex human behaviour will require an integration of these different approaches and the Unit is relatively unusual in having groups active in all these areas, concerned with a diversity of cognitive functions and with a strong commitment to linking these approaches to empirical data.

A second feature of the Unit's work from its inception has been a concern with applying psychological knowledge to the solution of real world problems. Rarely does psychological theory lend itself to simplistic application, and the solutions that the Unit has been able to provide takes many forms. In some areas (e.g. audition and speech) it is possible to deliver products which solve or contribute to the solution of practical problems. In other areas (e.g. driving and interacting with computers), the diversity of potential solutions means that ways have to be found for helping non-psychologists to understand the cognitive implications of the options they are considering. The Unit is starting to explore ways to bridge this communication gap, including the use of expert systems and simulations of cognitive functioning that designers can run in the task environments under consideration. Over the next five years we will assess the utility and power of these approaches to 'giving psychology away'. Moreover we expect the classes of communication being developed to have relevance to other problem domains where the application of psychological knowledge is far from simple or obvious (e.g. rehabilitation).

The Unit in its early days had a relatively strong biological emphasis, provoked in part by the military problems of the Second World War which generated an interest in environmental stressors such as heat and noise, as well as in factors such as fatigue and combat neurosis. During the 1970s, this aspect of the work of the Unit tended to become less prominent, but revived again with the advent of the group studying the relationship between emotion and cognition in normal and emotionally disturbed subjects.

I would see the development of research on cognition and emotion involving three phases. The first of these has been concerned with establishing that cognitive psychology does have a role to play in this area. I believe that we have already begun to show that the techniques and concepts of cognitive psychology can throw light on clinical problems, which in turn enrich the cognitive theory. The second stage is one of developing and testing theoretical models that incorporate both emotional and cognitive factors. This has already begun and is reflected in the many collaborations that have developed between the group whose primary concern is with emotion and cognition, and a range of colleagues in more mainstream cognitive psychology. I would see the third stage as involving the development and testing of methods of treatment. This has already started in the case of the proposed treatment for insomnia by Watts and Levey. However, in general it is realistic to expect the development and application of work in this area to be gradual, with theoretical insights leading first of all to experimental treatments, leading over a period of years to the development of standardised treatment packages and finally to their evaluation by multi-centre trial.

A second area in which the clinical and biological emphasis has steadily increased, is of course that of neuropsychology, an area in which the Unit has had, and continues to have considerable strength. Much of the theoretical progress in this area has come from applying cognitive models to single cases, often selected as having a very pure functional deficit. I believe that we are now developing our technical and conceptual skills to a point at which we are able to tackle patients with more than one deficit. This is an important development for two reasons, first because it increases the number of patients that can profitably be studied, and secondly because it means that we are in a much better position to tackle the complex cognitive deficits that accompany neurological diseases such as Alzheimer's Disease, Parkinson's Disease, and schizophrenia. This leads to a natural alliance between the cognitive psychologist, the clinician and the neuroscientist. This aspect of our work is likely to be further stimulated if the proposed Interdisciplinary Research Centre goes ahead. Even if it does not, the contacts made in discussing IRC proposals themselves seem likely to stimulate collaboration with our neurobiological and clinical colleagues in this area.

The major change that we are proposing over the next five years is of course the replacement of the Psychophysiology Section with a group concerned with rehabilitation. The problem of rehabilitating the brain-damaged patient is of course one of enormous practical and social importance, and one that has in the past been sadly neglected. We believe that developments in neuropsychology have now reached a point at which it can start to tackle these issues with some hope of success, and that the APU with its tradition of blending pure and applied research is in an ideal position to collaborate with the rapidly developing Cambridge Medical School in developing a centre of genuine excellence in this area. It will require the goodwill and collaboration of the regional administration, of the University Medical School, of our clinical rehabilitation colleagues, and of course the strong support of the Board. We have already begun local discussions and made initial contact with the Department of Health, and so far there appears to be considerable general enthusiasm for the proposal.

The proposed development will involve a substantial expansion of the clinical service at Addenbrooke's, with our own involvement being an integral part of such a newly-developed Rehabilitation Centre. Realistically, it will probably be four or five years before such a centre is up and running. Bearing that in mind, I would hope to see a gradual build-up of the Unit's rehabilitation commitment, initially relying on sub-optimal accommodation, but comprising by the end of the five-year period a team of some eight or ten scientists (see Section F). I would hope that by the time of our next progress report we would already be starting to demonstrate the fruitfulness of such an approach, while accepting that making real progress in this important but challenging area is likely to take substantially longer than five years. It is for that reason that an MRC Unit, with its remit for engaging in long-term research programmes is particularly well-placed for developing such an enterprise.

Categorisation of Publications

Over the period reviewed, the Unit has produced somewhere in the region of 750 publications, raising the problem of how to present them in a reasonably comprehensible and coherent way. We have opted to break them up according to the 10 broad subject areas covered by the report, and to present each set of publications after the relevant section of the report. We have tried to give further information about each publication by classifying them according to the following scheme:

A: Books. These range of course from sets of edited papers to major scholarly works that are likely to have an influence that goes far beyond that of most individual papers. I would particularly like to single out Shallice's "From Neuropsychology to Mental Structure" which is the first comprehensive analysis of the area of cognitive neuropsychology, and as such I think will become a classic. Secondly, I would like to draw attention to a book

that gives an account of the attempt by a team at the APU together with colleagues at St George's Hospital Psychology Department to build an empirical bridge between clinical problems and the concepts and methods of cognitive psychology, published as "Cognitive Psychology and Emotional Disorders" by Williams, Watts, MacLeod and Mathews. Finally I would like to mention Johnson-Laird's "The Computer and the Mind" which, by giving a very scholarly but well written overview of cognitive science, is a very good example of the Unit's concern to present science to the general public.

B: Journal Articles. These represent the solid core of our work, and comprise work that has been subjected to the normal processes of peer reviewing. The bulk of it is empirical, but we also include a number of theoretical contributions in this category.

C: Invited Chapters and Commentaries. This section comprises mainly articles provided in response to an invitation, often to take part in a symposium, or to participate in an open discussion on a particular topic. In some cases, the papers represent the output of small highly-focussed workshops which can be extremely productive in bringing the available experts in a topic together to address issues of common interest. Although they are often not rigorously refereed, in most cases the invitation to attend is strictly limited, and the freedom to write in a more speculative vein can be extremely productive.

D: Conference Proceedings. These clearly overlap with C, but differ in that they tend to have larger numbers of people attending and to be consequently more variable in quality. They can however be remarkably productive, as was the case with the proceedings of the two conferences on "Practical Aspects of Memory" which brought together a very wide range of previously disparate researchers with common interests in applied problems, and which have over the last 10 years served as a focus for work in this area. Furthermore, invited keynote addresses at such conferences can be very effective in communicating views to a wide audience.

E: Technical Reports, Theses and Tests. These represent publications that communicate technical information to a limited audience. This is an extremely important mode of communication in a number of applied areas, notably in those of psycho-acoustics, human-computer interaction and in research on practical issues of road transport. In terms of their practical impact, technical reports and papers presented at specialist meetings are often much more important in influencing policy than are papers in academic journals. In this section we also include reports in response to requests from government bodies such as the Cabinet Office or the Roskill inquiry on fraud trials. We also include unpublished PhD theses in this category.
F: Dissemination. Cognitive psychology has implications for, and draws from a range of disciplines within both the cognitive and biological sciences. We regard it as part of our responsibility to try to inform our colleagues about cognitive psychology, at the same time of course as attempting to learn from them. We are also fortunate in working in an area that is often of general public interest. This leads to the opportunity to talk about our work on radio and television, but also gives opportunities of informing the general public about cognitive psychology in slightly less ephemeral ways through our contribution to books for the general public. While we hope this categorisation will help the reader, it should be borne in mind that it is to some extent arbitrary, with a substantial number of papers being potentially classifiable under more than one topic and categorisation, while a few do not fit readily into any of the available categories.

ATTENTION Project 57 - Control and Function of Selective Attention

57.1 Visual Attention (Duncan)

In this reporting period there has been substantial progress in understanding the stimulus principles governing the efficiency of visual selective attention. The theory outlined in the last Report [7] has seen several major developments. In its present form [13] this theory integrates a wide range of experimental findings, relates sensibly to the requirements of normal vision, and suggests a possible neurophysiological implementation which is to be investigated in a new, collaborative project with N.I.M.H. in Washington D.C.

Much of the experimental work in this period has involved visual search [10, 11, 13]. Alternative accounts of search efficiency have rested on distinctions between (a) serial vs. parallel search; (b) single visual features

vs. feature conjunctions; (c) stimulus identification vs. local mismatch detection. Duncan's work suggests none of these is crucial. For all search materials, efficiency increases with (a) decreasing similarity of targets to nontargets, and (b) increasing similarity between nontargets. The interaction between these has been explored in detail. We must also distinguish similarity between possible stimulus alternatives, and similarity between stimuli within a display.

The findings suggest the following theory. A parallel stage of perceptual grouping and description is followed by competitive interaction between inputs, guiding selective access to awareness and action. An input gains weight to the extent that it matches an internal description (the attentional template) of the information needed to control current behaviour (hence the importance of target-nontarget similarity). Perceptual grouping encourages input weights to change together (weight linkage; allowing spreading suppression of similar nontargets). The idea of attentional templates allows control of visual selection to be indefinitely flexible. Depending on current concerns, inputs with any visual property (e.g. location, level of scale) can be relevant to behaviour.

Because of weight linkage, it should be easy to divide attention between visual inputs as long as there is strong perceived grouping between them. Preliminary evidence was described in the previous Report, and the prediction has now been confirmed in a long series of studies involving absolute identification of shape, orientation, spatial frequency, location, colour, brightness and texture. In each case it is very easy to identify two properties of the same perceived object in a brief display, but more difficult to identify properties of two different objects. This work also shows that, when attention is divided between objects, it does not matter whether they vary in the same or different attributes. (Something of an exception is colour, whose unique behaviour is still not understood.) Despite partial specialization of separate, parallel cortical areas for analyzing different visual attributes, there is no evidence for correspondingly parallel perceptual function.

Perceptual grouping may also be the key to the problem of tag assignment, or keeping together parts of the same whole in a distributed perceptual representation. Several connectionist models achieve accurate tagging by dealing serially with separate input locations, but the problem need not be solved serially, nor is common location always the important tag [26]. When attention is diverted, it is true that some stimuli (e.g. words) tend to produce percepts that are incorrect combinations of parts actually present, but others (e.g. single letters) do not [10]. Even when explicit identification of an unattended shape is at chance [6], the way that its parts are combined can influence its effects on a second, attended shape [10].

Project 58 - Executive Processes and their Pathology

58.1 Executive Functions and Intelligence (Duncan, Bourke)

An attempt is under way to link findings in neuropsychology, individual differences, and dual task performance into a unified account of executive function. In neuropsychology the "frontal lobe syndrome" reflects widespread disorganization in many aspects of behaviour. In individual differences, "intelligence tests" (even those with restricted content) show broad positive correlations with many different sorts of laboratory and real world activity. In dual task studies, interference is partly content-specific but also occurs between very dissimilar tasks. Duncan has suggested that all these phenomena reflect the widespread importance of a cognitive executive dealing with choice of goals in a complex environment [9, 12].

A common element between general intelligence (g) and interference between dissimilar tasks has been confirmed in a study of driving skills (see Section 73.1 [409]). Across a range of such skills, profiles of correlation with g and of dual task decrement are in excellent agreement. That frontal lobe damage reflects an impairment in g is generally denied; the reasons, however, seem poor, and new evidence suggests a link. A test has been developed to mimic, in normal subjects, one classic aspect of frontal disorder: neglect of a goal despite the fact that it is understood and the failure is appreciated. This test correlates about .5 with g, and is performed very poorly by frontal syndrome patients. Another new test which correlates even more strongly with g, though it measures RT rather than accuracy, uses fairly simple stimuli and contains no element of problem solving. In common with standard tests of frontal function this task requires frequent shifting of attention between different stimulus attributes, and again patients with a frontal syndrome perform very poorly.

Behavioural definition of the frontal syndrome is very loose, and despite the name, the underlying neuropathology is poorly understood. A grant from the Regional Health Authority has allowed us to assess a broad range of frontal impairments in 100 head injury patients, collaborating with Roger Johnson from the Rehabilitation Unit at Addenbrooke's Hospital. We use a structured clinical interview, a relative's questionnaire, and neuropsychological tests to study emotional, social, motivational and cognitive changes. Multivariate analyses will be used to define one or more "frontal syndromes", allowing principled selection of patients for future work.

In a final project Bourke is asking whether a single, general factor is sufficient to explain interference between different, dissimilar task pairs. By broad and systematic sampling of such pairs, this work assesses whether the order of primary task demands on the (hypothetical) general factor is consistent across secondary tasks. Results to date in fact suggest considerable consistency.

58.2 Executive Processes and the Frontal Lobes (Burgess, Shallice, Wilkins)

In an article covered in the last Progress Report, Norman and Shallice put forward the position that the action and thought selection process should be divided into two levels. 'Contention scheduling', the lower-level of the two, is a process which we held carries out routine selection of routine action or thought schemata/procedures. This selection process is, we argued, modulated by a higher level Supervisory System which can provide extra activation or inhibition to individual schemata in contention scheduling (see [1], chapter 14 for the application of the theory to frontal lobe disorders]. Three empirical studies have developed from this theoretical perspective:-

58.2a Incidental Utilisation Behaviour.

Lhermitte (1983) has described patients with frontal lobe lesions who when presented with a familiar object (e.g. glass, jug, comb, glasses) and no instructions will start to use the object. This behaviour is what one would expect from the operation of contention scheduling if Supervisory modulation of the system was grossly impaired as schemata specific to the objects would be triggered. However an alternative interpretation is that the frontal patient merely misinterprets the task demands of the situation. Shallice, Burgess, Schon and Baxter described a patient with bilateral medial frontal lesions who manifested utilisation behaviour when tested clinically using Lhermitte's procedure [20]. However he also exhibited it when familiar objects were present on

the testing desk while he was being instructed to carry out clinical neuropsychological tests. A demand characteristic artefact could therefore be excluded; an interpretation in terms of an impaired Supervisory System fitted the findings.

582b Disorders of Numerosity Judgements.

Concentration requires the operation of the Supervisory System to prevent the type of distracting triggering shown in the previously discussed syndrome. Performance on a test of concentration was found to be impaired following right frontal lesions [23].

58.2c Strategy Application Disorder Syndrome.

Shallice and Burgess argue that damage to the Supervisory System should produce problems for the efficient organization of a number of unrelated activities that have to be carried out over a period of time. A case-study of three head-injury patients with frontal lesions who had preserved intellectual skills (IQs of 120+) showed that they had severe difficulties on two tasks of this type. On the other hand, two of the patients were virtually unimpaired when other tasks sensitive to frontal lobe lesions were carried out.

These findings provide quantitative support for earlier clinical claims that a cognitive impairment producing severe judgement and organisation problems in everyday life can occur in certain frontal head injury patients who show no deficit on standard intelligence or frontal lobe problems. They also suggest that the Supervisory System fractionates with these patients having particular difficulties in the interruption of on-going behaviour by stimuli linked to intentions.

58.3 Frontal Lobe Memory Disorders (Burgess, Shallice)

In an extension of the above theory ([1] - chapter 15) it was argued that the description and verification processes involved in episodic memory retrieval would be evolutionarily linked to the functioning of the Supervisory System. A deficit of such processes can account for the characteristics of a highly selective memory problem analysed in a single case study [5]. The patient had suffered from a ruptured anterior communicating artery aneurysm; he had relatively preserved performance - measured in terms of items correctly retrieved - on a range of recall tests but performed in the amnesic range on many recognition tests and confabulated in both formal testing and on autobiographical recall. In a second study Burgess, Baxter, Rose and Alderman have described a new form of circumscribed delusional misidentification syndrome [4]. Neuropsychological, neurological and neuroradiological evidence supports frontal lobe involvement in the syndrome and a model related to the previously mentioned one was proposed which accounts for the paramnesic aspects of the phenomenon. Further evidence of an association between frontal amnesia and confabulation is provided by a study by Baddeley and Wilson [3].

58.4 Inference from Neuropsychological and Dual-Task Evidence to 'Normal' Functional Architecture (Shallice)

Shallice gave a detailed analysis of the assumptions necessary and the supporting evidence for drawing inferences from neuropsychological data for theories of normal cognitive functioning. No equivalent analysis has been carried out except by Caramazza, whose assumptions and conclusions - which are very different - are open to a number of criticisms ([1] chaps. 2, 9,10,11).

In conjunction with McLeod and Lewis, Shallice has studied two sub¬components of the language system which, on neuropsychological grounds can be considered isolable; the dual tasks of reading aloud and detecting a word from a target category in an auditory stream of words, which should require these two isolable sub-systems, can be carried out simultaneously with only a small loss in overall accuracy [22]. However two tasks (e.g. detecting a word in a target category on one ear while shadowing the input on the other ear), which on neuropsychological grounds would be assumed to require a common subsystem are strongly mutually interfering in normal subjects. That neuropsychological and dual task methodology independently lead to similar conclusions supports both approaches.

58.5 Rehabilitation Following Severe Neurological Damage (Burgess)

Two cases of behavioural dyscontrol following frontal lobe injury were successfully treated by Burgess in collaboration with Alderman of St Andrews ITospital in Northampton [25]. Detailed analysis of the symptoms and neurology of the patients demonstrated the utility of a cognitive neuropsychology characterisation of frontal lobe function - related to that discussed in section 1 -for the planning of appropriate treatment procedures. A second study [24] demonstrated that whilst treatment that focuses on a patient's action routines may have short-term success, to achieve long-term success and generalisation once the treatment framework is removed may require that the programmes focus on 'cognitive schemata'. Six single case studies are described where traditional behavioural methods failed to maintain improvement but once combined with a cognitive component the improvement was maintained at follow-up.

Project 59 - Analysis and Function of Conscious Awareness

59.1 Theoretical Treatment of Consciousness (Marcel, Shallice)

Marcel has edited (with Bisiach) a book on approaches to consciousness in philosophy, psychology and neuroscience [2] containing several contributions from the APU (see [34] and [368]). An introductory chapter by Marcel and Bisiach [32] reviews the problems of the topic for functionalist and biological science and the possible approaches. Marcel's own chapter [30] argues for the centrality, legitimacy, and causal status of subjective phenomenal experience, and also discusses some of the currently controversial issues in empirical studies of nonconscious processing (see also [28]).

Two publications [31, 38] discuss the philosophical issues and the problems for information-processing models of Intentionality - the content or "aboutness" of mental states such as images or propositional attitudes.

59.2 Consciousness and Information-Processing Theory (Shallice)

Shallice has argued that the standard method of attempting to relate consciousness with information-processing models is inappropriate [34]. On that approach it is assumed that consciousness corresponds to some aspect of the input, storage or output of some particular subsystem. Instead it is argued that consciousness corresponds to information multiply represented over a very short period of time in a number of different control systems.

59.3 Blindsight, Visual Masking and Dissociation of Indices of Awareness (Marcel, Price)

Following work reported in the last progress report [17], studies of blindsight and normal visual perception have become more integrated. If unilaterally cortically blind subjects showing 'blindsight' (nonconscious visual processing) are asked to indicate when they 'feel' that a light has been presented, there is a dissociation in

sensitivity, independent of criterion differences, between voluntary eye-blink, finger button-press, and oral responses. Blink responses become more accurate without feedback and transfer to the finger but not to verbal responses. There are separable effects of delay and modality of response. This has been replicated in normal subjects with threshold-luminance stimuli. The implied dependence of perception on response system or intention (under investigation), casts doubt on the assumed unity of phenomenal experience and the assumed equivalence of psychophysical indices.

This dovetails with work conducted by Price with Marcel on the measurement of awareness thresholds for stimuli under backward visual masking in normal subjects. When target-mask onset asynchrony is reduced, there are dissociations (a) between different indices of confidence, (b) between confidence and performance, and (c) between performance of different target discrimination tasks. Present results also suggest that evidence of nonconscious processing depends on the relation between stimuli and probe task.

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AUDITION

During the previous and current reporting periods, hearing research at APU was divided into three roughly equal areas — auditory warnings, auditory filtering and auditory perception. During the current reporting period the work on filtering and perception merged, and a project to develop a complete model of monaural auditory processing was begun. As a result, auditory research will be described under two project titles: 60. Analysis and Modelling of Auditory Perception, and 61. Auditory Warnings.

Project 60 - Analysis and Modelling of Auditory Perception

The auditory model under development at the APU has four stages: The first two stages perform spectral analysis via an auditory filterbank and neural transduction via a bank of "hair cells". Together, the first two stages form a cochlea simulation. The third stage performs phase alignment and produces a high resolution, stabilised image of the sound quality, or timbre. The fourth stage extracts the pitch and forms a global stabilised image whose motion corresponds to the pitch contours that we hear in music and speech. Together, the latter two stages simulate the auditory neural processing that converts the data flowing from the cochlea into a simulation of human auditory sensation. During the current reporting period Patterson has developed a complete computational version of this auditory model that can record and analyse the sound into pitch and timbre images without intervention [43]. During the next reporting period the intention is a) to improve the scientific basis of the model through experiments on pitch and timbre perception, b) to develop an auditory workstation and an auditory PC to promote the use of the model, and c) to develop collaborations to evaluate the model as a preprocessor for speech recognition.

60.1 Auditory Filterbank (Cosgrove, Edworthy, Holdsworth, Milroy, Nimmo-Smith, R Patterson)

In collaboration with the Royal Aircraft Establishment, Farnborough and the Institute of Sound and Vibration Research, Southampton, Patterson et al demonstrated that the Roex model of auditory masking could be used to predict signal threshold in complex noise environments like helicopters and trains [59, 55]. As a result, the collaboration was extended with the mandate to develop a time-domain, dynamic version of the filter, and an auditory filterbank that could serve as a preprocessor for speech sounds. This led Patterson and Holdsworth to develop a "gammatone auditory filterbank", which has the following advantages: The filter function was developed by auditory physiologists and its temporal characteristics have been shown to mimic those observed in cat data. When tuned to human parameters, the amplitude characteristic of the gammatone filter provides an extremely good approximation to that of the Roex filter which ensures that it will predict human masking data as well as the Roex filter. Finally, Holdsworth discovered a recursive implementation of the gammatone filter that makes the computation fast enough to be used as a speech preprocessor.

Following the development of a convenient interface, the filterbank has been distributed to about 20 sites in Britain and North America [63].

60.2 Neural Transduction (R Patterson)

At the start of this reporting period, Patterson programmed a simple static neural transduction mechanism that was sufficient to convert the output of the original auditory filterbank into the pulse ribbons used in our pitch and timbre research [47]. With the advent of the gammatone filterbank and more professional programming skills, a dynamic neural transducer was imported from Loughborough, creating our first truly viable cochlea simulation. These neural transduction mechanisms were used in conjunction with a lengthy series of experiments on monaural phase perception to produce a model of human phase perception that relates timbre changes to global parameters of auditory nerve firing [44, 56]. The Loughborough transduction mechanism includes compression and adaptation like those in the auditory system but it does not include the lateral suppression observed in the auditory system. As a result, the output of the mechanism tends to blur auditory features rather than sharpening them. This prompted Holdsworth to consider the form of the signal processing applied during neural transduction and to generate a mechanism which at one and the same time is simpler

and includes suppression. This "suppressive transducer" sharpens auditory features like the formants of speech. It is also particularly efficient and would appear to have considerable potential as a component in a speech preprocessor. A paper describing the "suppressive transducer" has been written and used as a basis for a patent application.

60.3 The Stabilised Timbre Image (R Patterson)

When a sound is periodic the neural firing pattern at the output of the cochlea contains a repeating pattern. The details of the pattern describe the timbre of the sound and the best description of the timbre is provided by combining the information from successive cycles. The original version of the auditory model [47] which suggested wrapping the output of the cochlea around a cylinder to concentrate the timbre information, proved to be computationally intractable. Subsequently, Patterson developed a triggered, quantised method of temporal integration that preserves the fine-grain temporal information during the longer term integration process. The mechanism is passive and produces a stabilised auditory image for periodic sounds the way the auditory system does. A computational version of this third stage now exists and a refined version of the first three stages of the model will form the initial auditory preprocessor that will be provided to the collaborators in the Esprit BRA project. A paper describing "quantised temporal integration" has been written and used as a basis for a patent application.

The work on the stabilised auditory image has attracted the interest of the Royal Aircraft Establishment, Farnborough, and we have negotiated a substantial research grant to develop the mechanism for speech stimuli.

60.4 The Stabilised Pitch Image (Nimmo-Smith, R Patterson)

In the model, the pitch information is extracted from the pulse ribbon flowing from the cochlea by wrapping the time line of the pulse ribbon into a logarithmic spiral, base 2. A periodic sound causes a subset of the pulses to line up on a specific spoke of the spiral and the orientation of the spoke determines the pitch of the sound [43]. Patterson and Nimmo-Smith investigated the properties of the spiral processor as a formal detection process and developed a staged argument to illustrate how this new, highly non-linear, detector is related to more traditional Fourier detectors and why it is more efficient for processing sounds like music and speech [51]. The MRC has applied for and received patent protection for the spiral processor [61].

Project 61 - Design and Evaluation of Auditory Warning Systems

Auditory warnings are used throughout industry because hearing is a 360° warning sense; no matter where the operator is looking, the warning sound will be detected. The need for auditory warnings was tragically exemplified by the crash of a British Airways passenger helicopter which did not have an auditory warning. While the pilots were looking for landfall in fog, the helicopter slowly descended into the sea. There was a flashing yellow warning light but they did not see it. An auditory low-height warning would almost certainly have averted this accident. In other industries, the problem is not a lack of auditory warnings but a plethora of excessively loud and strident warning sounds.

In the last reporting period, at the request of the Civil Aviation Authority, Patterson developed a set of guidelines for the production of auditory warning systems in aircraft and showed how the guidelines could be used to review four existing and proposed auditory warning systems. Subsequently specifications for three

warning systems were prepared for use in fixed-wing civil aircraft, in intensive care wards of hospitals and in military helicopters.

During the current reporting period, five auditory warning systems have been developed, two were designed to support British and International Standards; the remaining three were designed for use in specific applications [46, 48]. The warning sounds have the following general characteristics: A burst of three to eight sound pulses is used to construct a brief warning of 1-2 seconds duration. Each warning has a distinctive rhythm and melody, to prevent its being confused with other members of the warning set, and it is played with varying rates and keys to indicate the urgency of the situation. The spectrum of the sound pulse ensures that the warning sound is audible in the environment for which it is designed and that it has a distinctive sound quality. The following five paragraphs provide a brief description of the purpose and production of each warning set.

61.1 British and International Standards for Aircraft Warnings (R. Patterson)

At the request of the Civil Aviation Authority, a set of nine auditory warnings was developed for use in civil airliners. The purpose of this set of demonstration warnings was to illustrate the kind of warning sounds that would satisfy a Standard being developed by the Civil Aviation Authority for use in Britain and Europe. One of the primary purposes of this set of warnings was to illustrate that the design principles would not constrain manufacturers unduly and that the warnings would be highly distinctive. The warning set was the topic of an invited lecture presented to the Royal Aeronautical Society.

61.2 British and International Standards for Hospital Warnings (Edworthy, R Patterson)

At the request of the British Standards Institute and with the support of the Department of Trade and Industry, a set of warning sounds was developed for use in the operating theatres and intensive care wards of hospitals [53, 62]. The purpose of the warning set was to illustrate to British and International Standards organizations the kind of civilised, distinctive warning sounds that could be specified in a Standards document and used to replace the cacophony of buzzers and bells used currently. The standardisation process has now proceeded to the level of a Draft International Standard and should eventually become a Standard. The Standard specifies, and the demonstration warnings illustrate, two forms of hospital warning system. In one case there are only three sounds each of which indicates a whole category of problems and which are differentiated by their urgency. In the second form the three category sounds are supplemented by six specific warnings all of which indicate urgent conditions occurring in the topmost category. The design represents a compromise that enables each authority or hospital ward to tailor the system to their own needs by adding a small number of the highly urgent warning sounds to the general set of three category warnings.

61.3 Military Helicopter Warnings (Edworthy, Milroy, R Patterson)

This was a large project that extended over the entire reporting period and resulted in the production of three warning sets for three different helicopters (Sea King, Lynx, and Puma) [59]. The first set was developed for the multi-role Sea King helicopter and consisted of ten warning sounds. Like the civil aircraft set, it was designed to illustrate the wide range of distinctive sounds that could be constructed from within the guidelines. A learning experiment was performed with helicopter pilots and it showed that the new sounds were much more resistant to confusion than those being used currently in civil airliners [58]. The second set of warnings was produced for the Lynx helicopter and used to check the guidelines for setting the sound levels of the

warning sounds. Detection levels were measured in a Lynx helicopter shell and it showed thatPatterson's roex model of auditory masking was as accurate as the noise measurements that could be made beside the pilot's ear. In the course of these two studies, the helicopter pilots requested more urgent-sounding warnings to reflect the fast pace of life in the low-flying helicopter. Accordingly, a third and final set of warning sounds was developed for the Puma helicopter. Following tests to ensure the detectability and discriminability of these new warnings, they have been installed in test helicopters with two operational squadrons.

61.4 Civil Helicopter Warnings (R Patterson)

Following the crash of a British Airways helicopter, the Civil Aviation Authority asked the APU to produce a demonstration set of warnings for helicopters ferrying staff and supplies to North Sea oil rigs. The warnings were demonstrated to the operators of North Sea Helicopters who chose a modified subset of the sounds to meet a Civil Aviation Authority requirement for low-height warnings. APU and Racal Acoustics implemented the warning sounds in an airworthy device, and they are currently installed in more than 150 helicopters. A patent for warning sound production was submitted in the previous reporting period and has now been granted by British, European and American patenting authorities [60].

61.5 British Rail Trackside Warnings (Cosgrove, Milroy, R Patterson)

At the request of British Rail Research (Derby), a set of warning sounds for use by trackside maintenance crews to warn of approaching trains has been designed and tested. The correspondence between trackside warning function and the existing sound has been preserved by constructing all of the new warning sounds from components in the existing sound [57]. All four warning sounds had to be audible in the presence of no less than 46 different noise environments specified by British Rail Research [55]. A learning experiment was performed to show that the warning sounds are highly resistant to confusion [57]. The sounds have been delivered to British Rail in the form of an annotated demonstration tape; trackside testing will begin sometime later this year.

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LANGUAGE, SPEECH, READING AND WRITING

Project 62 - Recognition and Production of Spoken Language

62.1 Normal and Disordered Spoken Language Comprehension (Marslen-Wilson)

Research 1987-1989. After he joined the Unit in 1987, Marslen-Wilson continued on the programme of research into normal and disordered spoken language comprehension that he had been conducting since January 1985 in collaboration with Dr Lorraine Tyler, and which had been based since September 1985 in the Cambridge Department of Experimental Psychology. This was research supported by the MRC on a programme grant, originally awarded to Drs Tyler and Marslen-Wilson at a point when he was still a member of the Cambridge Psychology Department.

The work carried out under this programme grant combines research into language comprehension in normal adults and into the breakdown of this process in the adult aphasic. The research into the normal model has centred on the role of the mental lexicon in language processing, looking at how mentally represented knowledge of lexical form and lexical content is deployed in the on¬line process of speech comprehension. Working within the framework of the cohort model of lexical processing [97, 65], this research has focussed on three main areas: the nature of the input to the mental lexicon, the properties of the information-processing mechanisms underlying lexical access and selection, and the way lexical knowledge is deployed in higher-level processing. The results of this research show, first, that the processes of lexical access and choice are closely tied to the details of variation in the speech signal, suggesting a featural rather than segmental input to the

lexicon, and supporting a view of lexical form representations as structured arrays of features rather than simple strings of segments (or phonemes). The second group of studies confirm the claim that lexical processing is based on a process of competition among simultaneously active candidates, establishing the principle of the contingency of perceptual choice. The third strand of the research on normals, closely linked to developments in the aphasia research, has looked at the processing of morphologically complex words in utterance contexts, investigating basic questions about the processing functions of word-stems and word-affixes in parsing and interpretation.

The research into aphasic disorders of language has centred on the development and validation of the concept of the on-line processing profile: that is, the complete profile of each patient's dynamic processing capacities in the domain of spoken language comprehension. This has resulted so far in the development of 25 tests, consisting of 14 tests of basic on-line processing capacities, ranging from the initial analysis of the speech signal to the construction of higher-level interpretative representations, together with 7 additional "off-line" tests of the same capacities, and 4 tests screening for possible memory problems.

In addition to this research based in Cambridge, approximately 25% of Marslen-Wilson's time has involved collaboration with researchers at the Max-Planck Institute in Nijmegen. The topics here, also all involving aspects of spoken language comprehension, include the representation of lexical form, syntactic parsing in Dutch, German, and English, and research on large-scale lexical databases, lexical statistics, etc.

During this initial period he has begun to build up collaboration with researchers in the Unit - especially in connection with the ESPRIT BRA proposals. This has involved Patterson, Cutler and Norris. In the neuropsychological domain the research (with Dr Tyler) has benefited in particular from discussions with Patterson.

Collaboration within the Unit. The planned research described above overlaps in many ways with the skills and interests of several members of the Unit. The research on lexical access in the speech domain is complementary to the research interests of Cutler, Norris and Patterson. The ESPRIT BRA project, now about to get underway, will provide an excellent environment for collaboration and cooperation with these individuals. The emphasis on acoustics-phonetics and on computational modelling in the BRA project is a useful counterpoint to the research directions Marslen-Wilson will be taking.

The involvement of the Unit in the proposed Rehabilitation Centre, and in related on-going work elsewhere, suggests another domain where collaboration with other members of the Unit (especially Baddeley and K Patterson) can naturally and profitably develop. This is in addition to the long¬standing contacts already existing with K Patterson, and, to a lesser extent, with Marcel and Shallice.

62.2 Studies of Lexical Segmentation (Butterfield, Cutler, McQueen, Norris, K Patterson, Williams)

The primary goal of Cutler's research during the past few years has been development of a model of the prelexical stages of speech recognition, a model which is sufficiently general to be language-universal, but sufficiently detailed to account for language-specific phenomena. Joint research with Norris and with colleagues in Paris established that speech segmentation procedures differ in speakers of French and of English [81]; the syllable functions as an effective segmentation unit for speakers of French, but not for speakers of English. This can be explained in terms of differences in phonological structure between the two languages. Subsequent

studies have confirmed that even in completely bilingual speakers of French and English one or other segmentation procedure is the more basic [83]: only those bilinguals who accept that French is their dominant language use syllabic segmentation; bilinguals in whom English is more dominant do not.

Norris and Cutler proposed [105] that this difference reflects the importance of the rhythmic structure of language in guiding prelexical segmentation. This led to the development of a model of segmentation in English and rhythmically similar languages, according to which segmentation in such languages is guided by stress rhythm; the speech stream is segmented at the onset of rhythmically strong syllables. The model received substantial experimental support from studies using a new task, "word-spotting" [84]. These studies showed that when detection of a real word embedded in nonsense requires assembly of speech material across a putative segmentation point, i.e. the onset of a strong syllable, detection is delayed; but assembly of speech material across boundaries which according to the model are not segmentation points causes no such delay.

Parallel studies conducted on the Alvey grant MMI 069 demonstrated that the lexical segmentation strategy proposed for English is well supported by the structure of the English vocabulary [166, 78]; most words in English begin with strong syllables, and in typical spontaneous speech nearly all lexical words start with strong syllables. Since what makes a syllable strong or weak is the nature of its vowel, the proposed segmentation strategy is driven initially by perception of vowel nuclei, and it is important that syllable onsets be independently derivable; for this reason experimental demonstrations that syllable-initial consonant clusters are treated as integral units in segmentation [164, 85] provided valuable supporting evidence. Further supporting evidence came from studies of naturally occurring and experimentally produced juncture misperceptions, which showed that listener errors can be predicted by the strong syllable hypothesis [162]: both in spontaneous slips of the ear and in experiments on hard-to-hear speech, it was found that juncture misplacements which erroneously inserted a word boundary before a strong syllable, or deleted a word boundary before a weak syllable, were common, while misplacements which erroneously inserted a word boundary before a weak syllable, or deleted a word boundary before a strong syllable, were rare. This line of research on segmentation is reviewed in [129] and [130].

In associated work, central theoretical issues involved in modelling speech recognition at this level were addressed. First, studies of the availability of lexical information to a phoneme detection process [82] showed that effects of lexical-level processing can be made to come and go according to the requirements of the experimental situation; for instance, making the experimental materials very homogeneous in segmental structure removes lexical effects, while introducing variety encourages them. This result suggests that listeners can switch attention between levels of processing, and that such switching can be more elegantly accommodated by a serial rather than an interactive information-processing structure. Supporting results have been obtained by McQueen [168] in a phonemic categorisation task. Second, it was shown by Norris and Cutler [106] that, contrary to previous reports, listeners can respond to phoneme targets more rapidly than to syllable targets. This result supports the intuitive hierarchy of potential segmentation units such as the phoneme and the syllable in levels of representation. Third, Cutler, Norris and J Williams showed that listeners can draw on quite detailed knowledge of the phonological structure of their language in making segmentation decisions [77]. These theoretical issues in speech recognition processing are addressed in [182] and [49].

62.3 Studies of Prosody in Speech Recognition (Butterfield, Cutler, Nimmo-Smith, Norris, Smith)

Although this line of research has tapered off since the main focus has moved to pre-lexical segmentation, a number of continuing projects have produced useful results during the time period of this report. Studies of noise-masked speech showed that listeners can exploit speech timing patterns to extract information not only about stress rhythm but also about where word boundaries occur [117]. Phonetic categorisation studies with minimal stress pairs such as "tigress"-"digress" suggested that word prosody is represented in the lexicon and can affect word recognition decisions [73]. The importance of prosodic information for sentence-level processing was confirmed in phoneme-monitoring studies using spontaneous speech (which is prosodically fragmented) as well as read speech (which is prosodically fluent) [100]. Separate manipulation of the prosodic dimensions of rhythm, pitch and intensity showed that it is necessary that the prosodic structure of an utterance be internally coherent; listeners fail to extract useful information at all from the prosody when the separate dimensions convey conflicting information [163]. Finally, the development in young children of the ability to extract such prosodic information was studied; results suggest that in acquiring the ability to exploit sentence-level prosodic information in sentence recognition, children need first to acquire representations of semantic structure within utterances [86].

Theoretical explorations in this area have principally concerned cross-domain implications between psychological and phonological theory. For instance, is the failure to find syllabic segmentation effects in English [81] relevant to the status of the syllable as a construct in the phonology of English? It is argued that psychological studies of speech processing can not constrain phonological theory, in the same way that phonological theory itself can have no direct implications for psychological modelling [76, 131, 135]. A research finding is relevant only to the theoretical framework within which it was conceived, and a theory can only be tested by experiments which are designed directly to test it; although the psychological theory of language processing needs to draw upon detailed knowledge of linguistic structure, and linguistic theory must not ignore the characteristics of language performance, the two bodies of theory are separate.

Project 63 - Computational Modelling of Human Speech Recognition and Reading

Although speech is a time-varying signal, conventional feed-forward networks have no way of handling the temporal component of speech directly. Consequently, such networks tend to be unable to generalise appropriately in the time domain. For example, simple feed-forward nets either have to be lined up with the onset of words in the signal, or have to be taught to recognize words in all possible positions. For the same reason they are very poor at accommodating temporal variability in the signal, such as might be caused by changes in the rate of speech. Both of these problems have been overcome by developing a connectionist model of human speech recognition based on a dynamic net [149]. A dynamic net incorporates feed-back links with time delays. This enables the network to process new input in the context of its processing of prior input. The network can therefore process its input successively in small time slices rather than requiring the entire input to be analysed simultaneously. Unlike the TRACE model, for example, the net can identify words in continuous input without the need for duplication of word nodes. Also, the net is very tolerant of temporal variability in the signal. Finally, the strongly left-to-right nature of the dynamic net means that it provides a natural model of the left-to-right, or 'cohort', behaviour observed in human speech recognition.

63.1 Connectionism and Modularity (Norris)

We tend to think of connectionist models as being highly interactive. However, connectionist models force us to consider how complex tasks can actually be learned as well as performed. But learning in very large unstructured (interactive) nets is very slow, if not impossible. Learnability considerations lead to the conclusion that complex tasks can only be acquired by very modular and highly structured learning systems. For example, work on a connectionist model of an idiot savant date calculator [103] demonstrates how a relatively simple task can only be learned by a network whose structure parallels the stages of the date calculation algorithm. The task can not be performed by a simple net with a single layer of hidden units. The only way we could ever learn a really complex task such as language is by using a very modular and highly structured learning system. This work on idiot savant date calculators also demonstrates how individuals with limited arithmetical skills and little or no explicit knowledge of facts about dates can perform such a complex task as date calculation. The network only needs knowledge of the days in each month and a few anchor dates to provide it with training information. It then learns to calculate dates by internalising a set of table look up procedures which require no arithmetical skills or explicit knowledge about dates.

Further work on modularity shows how the power of back-propagation networks introduces new and more powerful bottom-up models. Elman and McClelland (1988) have recently presented data which appear to provide categorical evidence for the top-down influence of lexical information on phonetic processing. However, Norris [150, 151] has shown how very simple bottom-up models using back-propagation can account for their data. Interestingly, there appears to be no equivalent model of the classical information processing box model form which can account for the same data without assuming that there is some interaction between processes.

Project 64 - Analysis and Modelling of Normal and Impaired Reading and Writing

64.1 Modelling Normal and Impaired Recognition and Pronunciation of Written Words (K Patterson)

Until recently, this area of research (like most) relied mainly on descriptive, information-processing models [154, 153]. Such theories allowed significant progress towards a broad conception of the inter-relationships between different components of a language system; but they did not make specific proposals about how a particular cognitive operation would be computed, and so yielded no quantitative, testable predictions.

With the advent of connectionist (also known as parallel distributed processing, or neural net) modelling, one can (a) make hypotheses about the precise nature of the computation; (b) implement these computations in a computer simulation; (c) assess the simulated results in the light of data from normal subjects performing the same task; (d) "damage" the computer model in various ways; and (e) assess the performance of the "lesioned" model against data from neurological patients with relevant impairments.

A connectionist model of translating English print to pronunciation developed by Seidenberg and McClelland (1989) is one of the most comprehensive PDP models thus far implemented, in terms of both the size of the data base and the range of performance simulated. The model assumes that words (both written and spoken, both known and novel) are represented as patterns of activation distributed across large sets of simple, neuron-like elements. Learning involves modification of weights on connections amongst these elements. The

existing model demonstrates that a single computational procedure may be able to deal with three types of English letter strings which were thought to require multiple procedures for spelling-sound translation: regular words (words which obey typical spelling-to-sound "rules", like HINT), exception words (words which break these rules, like PINT) and nonwords (previously unencountered letter strings, like RINT).

Patterson, Seidenberg and McClelland have explored various forms of damage to the trained network [155] and have achieved some success in simulating one major variety of acquired reading disorder, surface dyslexia (see [66], in which the patients retain virtually normal ability to name regular words and nonwords (HINT and RINT) but tend to "regularise" exception words (pronouncing PINT to rhyme with "hint").

64.2 Experimental Work on Neurological Patients (Marcel, K Patterson)

64.2a. Marcel and Patterson have now finished a large study of phonological dyslexia, where reading of familiar words is virtually normal but reading of even simple new words or nonwords is impaired, and a paper is in preparation [95]. The study involved implicit and explicit tests of the procedures necessary to read aloud nonlexical letter strings: segmentation of orthography, assignment of phonology to each segment, assembly of phonological segments into a spoken syllable. These tests also bridge the methodological gap between acquired dyslexia and studies of children's acquisition of literacy. The results show (a) deficits and lexical effects in orthographic segmentation and (for all patients) in phonological assembly, and (b) for some patients, a superiority in oral reading of nonwords which sound the same as real words (phood > thood). These data challenge the need to postulate a deficit in grapheme-phoneme retrieval and support models where the various operations required to read a nonword are not independent of word knowledge. They also suggest that spontaneous (lexical) speech may involve construction from sublexical segments rather than retrieval of addressed, lexically complete phonology.

64.2b. Two right-handed teen-aged girls with onset of encephalitis after the age at which normal lateralisation of function is expected to occur had complete hemispherectomy operations (one left, one right) at age 15. A study of their reading abilities at age 17 [109] showed a pattern of word recognition and pronunciation skills for the right hemispherectomy case that was somewhat delayed (i.e. characteristic of an 11- or 12-year old normal child rather than a 17-year old) but in no way deviant: she did not have poor performance on any of the many sub-components of reading skill tested. The left hemispherectomy case, on the other hand, not only had extremely poor performance on all language and reading tests but showed a highly distinctive reading pattern (oral reading restricted to highly frequent words referring to imageable, concrete objects; semantic errors in naming single words; total inability to compute phonology for unfamiliar letter strings) that characterises some adult vascular cases with very large LHem lesions. There has been substantial debate (see for example [124]) as to whether this pattern of reading performance, known as deep dyslexia, reflects the reading capabilities of the RHem. The observation of this pattern in a patient with only a RHem favours the RHem theory of deep dyslexia.

64.3 Neuropsychological Analyses of Semantic Memory (Burgess, K Patterson, Shallice)

64.3a. Theoretical Analyses. The positions on the organization of semantic memory for which Shallice argued in a theoretical paper [158] on a number of issues, particularly on the separability of visual and lexical semantics,

have been criticised by Riddoch et al (1988). In a reply [112] Shallice showed that their own positive evidence for their position had serious flaws and that certain key results had not been explained from their perspective.

64.3b. Pure Alexia. An analysis of a letter-by-letter reader [113] questioned the generality of previous accounts of pure alexia by Warrington and Shallice (1980) and by Patterson and Kay (1982), as this patient was able to access certain lexical and semantic information about written words when unable to explicitly identify them. This characteristic was viewed as arising from a severe but not complete impairment of access to the semantic system.

64.3c. Rapid Serial Visual Presentation. McLeod, Shallice, Watson and Burgess have shown that normal subjects attempting to identify words from a very broad semantic field (objects not found in a house) that occur in a rapidly presented list (exposure duration = 160 msec per item) make semantic and visual errors like those found in certain pathological cases (semantic access dyslexia and deep dyslexia) [94]. In a control experiment it was shown that the rate of occurrence of semantic errors is too great to be plausibly attributed to a forgetting process over the 1-2 sec time course of a trial. It is suggested that the errors reflect inadequate access processes.

64.4 Connectionist Modelling of Semantic Access Processes (Shallice)

With G Hinton, Shallice has explored the effect of lesioning a connectionist net to see whether the lesioned net showed properties qualitatively similar to ones exhibited by patients and for which no convincing account is available within the standard cognitive neuropsychology framework [90]. The net mapped orthographic input into semantic features. Lesions reproduced the co-occurrence of semantic, visual and mixed visual and semantic errors characteristically found in deep and semantic access dyslexia. They also showed the relative preservation of categorical discrimination when precise identification is lost, a phenomenon found in semantic access dyslexia. To our knowledge, this is the first time that non-transparent neuropsychological phenomena have been mimicked by lesions to connectionist nets.

64.5 Experimental Work on Normal Readers (K Patterson)

One of the strengths of APU research has always been the combined use of normal and neuropsychological data to address theoretical questions. Two of the issues raised by a comprehensive review of mechanisms of spelling to sound translation [153] are now being investigated in studies of normal readers via two collaborations.

64.5a. If (as suggested by the neuropsychological data) the normal reading system offers several alternative routines for translating print to pronunciation, then manipulating a normal subject's strategy either explicitly by instruction or implicitly by the nature of the reading task ought to change patterns of performance. Monsell (University of Cambridge) and K Patterson have demonstrated large individual differences in subjects' ability to exert strategic control over procedures for word naming, with meaningful correlations between these differences and other aspects of reading performance.

64.5b. If (as suggested by one interpretation of both real and computationally simulated data) the pronunciation errors of surface dyslexic patients (e.g. PINT pronounced to rhyme with "hint") are based on sub-asymptotic activation in the phonological system, then normal subjects naming words under unnaturally

speeded conditions might be expected to produce similar errors. Data from the first of several studies by Seidenberg (McGill University) and K Patterson support this hypothesis.

64.6 Rehabilitation (K Patterson)

There has been a limited amount of work at the APU on techniques of rehabilitation [91, 92] and theories of rehabilitation [140] based on cognitive neuropsychological analyses of language and reading deficits. This is partly due to the difficult and time-consuming nature of well-designed research on efficacy of treatment; but it is also due to the fact that there has been no adequate centre for rehabilitation research at Addenbrooke's Hospital to enable such work. Plans to establish such a centre are described later in this report. Given the wealth of analytic data on acquired disorders of reading that now exists, using such information to develop and evaluate therapy is a natural area for future work.

64.7 From Pronunciation to Print: Writing and Spelling (Burden, K Patterson, Wing)

In parallel with work on reading and its disorders, we have been investigating writing and spelling skills, again in both normal and patient populations. Case studies of stroke patients have been informative about both central [107] and peripheral [111] aspects of the writing process. A research student at the APU (V Burden) has just completed three years' research on neurologically normal adults who have abnormally poor spelling skills (e.g. [72]). Although the problems of such subjects have in the past been described as restricted to writing, more detailed investigations reveal these people to be at or even below the limit of the normal range of adult performance on other skills such as reading speed, short-term memory and phonological manipulations. The results have important implications for theories of the inter-related development of these aspects of cognitive ability.

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LEARNING AND MEMORY

Project 65 - Human Learning and Memory in Normality and Pathology

65.1 Working Memory (Baddeley, Gathercole, Logie, Valentine)

Working memory is the system responsible for the temporary storage and manipulation of information used in performing a wide range of cognitive tasks such as reasoning, comprehension and learning. A previously-developed model involves three components, a controlling Central Executive system, assisted by two slave systems, the Articulatory Loop which is responsible for verbal information, and the Visuo-Spatial Sketchpad that holds and manipulates visual images.

Baddeley, in collaboration with Vallar in Milan and Wilson in Southampton, has continued to explore the function of the Articulatory Loop, in particular studying the cognitive performance of patients with specific deficits to this component of working memory. Two patients have been studied in some detail, one showing a

clear deficit with certain types of long and complex sentence, but good comprehension otherwise [197], while the second [199] shows a much more dramatic impairment in comprehension of all but short sentences.

The nature of the subvocal rehearsal process has been explored in a collaborative study with Wilson [198], on an anarthric patient who had lost any capacity to speak but retained normal language as reflected in comprehension and writing. He proved to have quite normal phonological short-term memory, suggesting that overt articulation is not necessary for rehearsal. Similar results have subsequently been obtained by Logie [269] and in a study by Bishop and Robson (1989) of congenitally anarthric children.

Another extensive series of experiments by Logie and Baddeley has explored the role of the articulatory loop in counting, suggesting that subvocalization is necessary for accuracy, even in well-practised adults [217]. Work has continued on the disruption by unattended sound of memory for visually presented material, in collaboration with Salame in Strasbourg. We have shown that disruption occurs from both vocal and instrumental music [232] but not from noise, regardless of loudness [231]. The disruption appears to be at the level of short-term storage, rather than perception [195], possibly having implications for the role of short-term phonological memory in speech perception.

A new development in the study of the functioning of the Articulatory Loop concerns its role in long-term phonological learning. Patients of the type described had until recently been assumed to show normal long-term learning. Baddeley, Papagno and Vallar have shown that an exception to this occurs when the new learning is phonological in nature, for example learning the vocabulary of a foreign language. Under these conditions we found a dramatic impairment in new learning [194]. We are currently exploring the role of this system in normal subjects by requiring them to learn foreign language vocabulary while suppressing subvocal rehearsal by articulating some irrelevant sound. Preliminary results are encouraging [228], suggesting that this system may be specialised for new verbal learning.

We further speculated that this short-term phonological system is crucial for a child's learning of its own native language. Evidence supporting this comes from a study by Gathercole and Baddeley of children who had been previously categorised as "language-disordered". We found that the most striking cognitive deficit shown by these children was in performing a task requiring them to hear and repeat back unfamiliar sequences of sounds, as in repeating a novel word. Eight-year-old language disordered children who had reading and vocabulary ages of six, performed this task at the level of four-year-olds [255].

Non-word repetition can plausibly be assumed to depend on temporary phonological storage, that is on the Articulatory Loop. We have been further exploring its capacity to predict language development in a longitudinal study of children who were tested on non-word repetition, reading and non-verbal intelligence on starting school aged four, and one and two years later. We find that non-word repetition is the best predictor of their vocabulary levels both initially and subsequently, and that non-word repetition capacity is also a reasonably good predictor of their reading score at age six. The principal investigator on this project, Susan Gathercole, has now moved to a Lectureship at Lancaster, and is continuing the project on an MRC project grant in which Baddeley is involved as a collaborator.

The concept of a Central Executive has been further developed [185], partially by adopting a model of attentional control devised by Norman and Shallice [33]. The model has the advantage of explaining some

striking but hitherto puzzling results concerning the capacity for generating random sequences of items such as letters. This in turn suggests that random generation may provide both a useful measure of Central Executive capacity, and a suitable method of disrupting the functioning of the Executive. This was tested in two experiments carried out jointly with Robbins and students from the Psychology Department, concerned with the analysis of chess skill (Robbins et al., in preparation). The first study required average or expert players to remember chess positions while performing secondary tasks expected to disrupt the operation of the Articulatory Loop (articulatory suppression), the Sketchpad (spatial tapping) or the Central Executive (random generation). Both average and expert players showed the same pattern of no disruption from articulation, together with clear impairment in memory for positions that were seen and recalled during spatial or Central Executive processing. A second study used a similar method to study the choice of optimum move given a predetermined position, and found essentially similar results.

These findings are consistent with other research, funded through a collaboration with the University of Illinois, that has shown that dual task methodology based on the working memory paradigm can be used to tease apart the components of a complex skilled task; one instance is that of a complex computer game requiring many hours to master. Here, we found that the working memory approach gave a better analysis of the task than existing workload measures based on subjective estimates of task difficulty, or on single interfering tasks [218, 268].

65.2 Working Memory and Dementia (Baddeley)

Collaborative research with colleagues in Milan [233] and Pittsburgh has been concerned with the hypothesis that patients suffering from Alzheimer's Disease show a particularly marked deficit in long-term learning and in the Central Executive component of working memory. The Central Executive deficit was tested by using a task in which patients and elderly and young controls were required to coordinate two tasks, one of the assumed primary functions of the Executive. Tasks were chosen so as to load on separate subcomponents of working memory, and to be adjustable so that the overall error rate was equivalent for our three groups. Hence in one critical condition subjects combined a visuo-spatial tracking task with concurrent immediate memory for digits. Despite the fact that the level of difficulty of the two tasks was adjusted across groups, the Alzheimer patients showed dramatic impairment in combining the two, whereas the normal elderly were no more impaired than the young [193]. In a subsequent longitudinal study, dual-task performance was shown to decline much more precipitously than performance on either of the constituent tasks.

A three-way NATO-funded collaboration between Milan, UK and Pittsburgh has further explored the hypothesis of a two-component deficit. Detailed analysis of individual cases suggests that although memory and Central Executive deficits are characteristic, substantial differences between patients occur. Whether this represents differences in the disease process itself, or differences in the inherent vulnerability of different patients is an important but as yet unresolved question.

65.3 The Neuropsychology of Auditory-Verbal Short-Term Memory (Shallice)

In a review paper [260] with Vallar, Shallice has shown that all patients so far described with a selective span deficit, and for whom word comprehension is preserved and articulation is relatively spared, are well characterised as having an impairment of the phonological input buffer within a multiple stores/working

memory framework. With Butterworth and Watson [252] Shallice has shown for one STM patient that retrieval from the phonological buffer interacts with retrieval from a semantic trace; retrieval from the two systems is not independent as more traditional theorising would suggest.

Shallice has edited with Vallar [189] a book on all aspects of the short-term memory syndrome including its relation to models of normal short-term memory and of normal language comprehension.

65.4 Long-Term Learning and Memory Deficits (Baddeley, Emslie, R Green)

It has in recent years become increasingly clear that long-term memory does not reflect a unitary system, but rather a number of different subsystems. The most powerful evidence for this fractionation has come from neuropsychology, leading in turn to a more adequate understanding of the memory deficits shown, and a further development of diagnostic clinical tests.

A good example of this concerns the project started some years ago that was concerned with estimating the extent to which existing clinical tests were good indices of the memory problems patients encounter in their everyday life. It suggested that the relationship was in many cases rather poor, but further pointed out the limitations of questionnaire measures - some patients simply forget how bad their memory is. Work by Wilson at Rivermead Rehabilitation Centre in Oxford led to the development of the Rivermead Behavioural Memory Test (RBMT) which consists of a series of subtests, each comprising a model of some everyday memory task, such as remembering a new person's name, finding a route, or recognizing a face. The test was a logical extension of our own project, and we collaborated in developing and validating the test and collecting norms (supported by an MRC grant to Wilson). The test was validated against many hours of therapists' observations of memory lapses in brain damaged patients, and proved a valid and very acceptable clinical instrument which is now being widely used throughout the world [261, 241]. Norms for the elderly have just been completed, and a children's version is currently under development by Wilson, again funded by an MRC grant.

Further work concerned with the analysis of long-term memory deficits in patients showed that existing tests in clinical use are unlikely to detect deficits in autobiographical memory, the capacity of a patient to remember aspects of his or her earlier life. In one study we tested a range of patients using the technique of providing a cue word such as "river", and asking the patient to recollect an associated personal experience. This provided rich data, allowing us to subcategorize patients, and in particular highlighting the association between damage to the frontal lobes, defective operation of the Central Executive in working memory, and a tendency to confabulation [248]. The cue word method is however unsatisfactory in many ways, and in collaboration with Kopelman (then at the Institute of Psychiatry) and Wilson we devised a structured interview that probes the patient's recall of personal facts from various earlier periods of life (such as the names of teachers, the addresses lived in as a child) coupled with the capacity to recollect episodes that occurred during that stage of life. The autobiographical interview proved sensitive and easy to use, with the readily scorable autobiographical facts as good an indicator as the episodes [215]. A subsequent study by Dritschel, M Williams and Baddeley used a much larger sample of normal subjects has used cluster analysis to investigate the relationship between memory for personal events and memory for general semantic facts such as the names of Prime Ministers or animals [209]; results suggest that autobiographical and semantic memory reflect domains within a complex system rather than the output of separate modular systems.

It is often useful in assessing a brain damaged patient to have some indication of probable premorbid intelligence. At present there are relatively few ways of measuring this, and we have devised a further test that relies on the fact that the capacity to recognize whether a string of letters is a real word or not appears to be very resistant to brain damage. The Spot-the-Word test involves presenting subjects with pairs of items of which one is an invented non-word such as "strubbage" while the other is a real word. The words vary in frequency from the common such as "oasis" to the relatively obscure, e.g. "thole", and the subject is required to tick the real word. The test correlates very highly with other estimates of vocabulary, and is readily accepted by patients. General population norms have been collected by Emslie and Baddeley, and collaborative work is underway to validate it against a full WAIS intelligence scale. It has been used with elderly, depressed, demented and schizophrenic patients, and we plan to use these data further to explore its robustness to the effects of brain damage. We are however now reasonably confident that it will provide a useful brief estimate of premorbid intelligence, or indeed of current intelligence in normal subjects.

65.5 Memory and Schizophrenia (Baddeley)

The development of new tests such as the Rivermead Behavioural Memory Test suggests the possibility of re-examining the memory function of patient groups. In collaboration with McKenna at Leeds, Baddeley has begun to study the memory performance of schizophrenic patients. Preliminary results are quite striking in suggesting that about a quarter of the patients studied show severe memory impairments, impairments that may be disproportionately greater than other cognitive deficits shown. A second notable feature of the study is the hetereogeneity of cognitive deficit shown in this group; as in the case of the previously-described Alzheimer patients, this raises the question of whether the variability stems from differences in the disease process, or differences in the underlying vulnerability of individual patients. We hope to explore the relationship between cognitive deficits and underlying neurological impairments, possibly using PET scanning. McKenna has now moved from Leeds to Fulbourn Hospital Cambridge, which should make collaboration logistically easier.

65.6 Connectionist Modelling of Memory (Houghton, Jackson)

Since arriving at the Unit the majority of Houghton's research has been in the area of computational modelling of psychological phenomena. The particular models he has been developing fall within the recently emergent "connectionist" paradigm. These models, though implemented on serial, digital computers, attempt to use processing modes inspired to a large degree by neurophysiological findings. They thus contrast both conceptually and computationally with the more familiar "symbol-manipulation" paradigm in which psychological processes are modelled as sequential, quasi-logical operations on structures built from alphabets of passive symbols.

The work falls into two main areas - (a) learning and recall of sequences (with particular emphasis on spoken language) and (b) "concept formation" using unsupervised learning algorithms. The major focus has been on the first of these two areas, though there is a certain amount of overlap due to the use of mathematically similar constructs in both areas.

65.6a Learning and Recall of Sequences. In the work on topic (a) Houghton has attempted to improve on previous connectionist models which deal with the problem of temporally (as opposed to spatially) patterned information. Temporal order is a serious problem for the connectionist approach because its basic theoretical

vocabulary contains no ordered objects (such as lists), which the symbolic computational approach, for instance, takes for granted. The standard strategy in much previous work has actually been to avoid the problem by trying to recode temporally structured information (such as language) into a spatial form. Recall of a sequence in such models reduces to the recall of a spatial pattern, and the problem of converting this pattern into serial behaviour is ignored. (These models generally do not learn sequences either but have to be set up "by hand".) The model produced, called the Competitive Queuing model, learns sequences (in particular syllables, represented as strings of phonemes) by simple exposure and the use of a "Hebbian" weight change rule (intended to represent changes in synaptic connection strength between cells). Recall of the sequence is genuinely temporal, the sequence of elements appearing one after the other at output. Despite this, the initial activation of sequence elements occurs in parallel, up to a point. This is in accord with available evidence and the model represents a solution to the apparent paradox that groups of elements of a serially-ordered behaviour appear, at some level, to be accessed in parallel.

65.6b Concept Formation. A second project looks at the use of algorithms for the formation of "feature detectors" in neural networks, investigating the possibility of developing them in concept learning models. Another intriguing possibility is to develop "temporal" versions of these algorithms, which would then generate detectors for temporally, rather than spatially defined patterns. The work has developed to the stage of producing a model which (in the spatial version) is capable of simulating some features of categorical perception. This model can also perform unsupervised associative learning between two "conceptual maps". It can perform this learning in situations which appear to defeat at least the simplest of "supervised" learning rules (i.e. those which require an omniscient "teacher"). Preliminary work on a temporal version (using English syllables as input) produces a map of the input based on the temporal pattern with similar sounding syllables being represented at spatially adjacent locations in the map. This is consistent with data on the production of malapropisms. As well as offering explanations for such data, this work offers the possibility of seeing how the mental lexicon can spontaneously self-organise along phonological dimensions.

65.7 Modality and Memory (Conway, Gathercole)

65.7a Short-term memory. A series of experiments assessing the nature of differences between recall of recent auditory and visual events was carried out. In particular, investigations of the effects of post-list articulatory suppression showed that the auditory advantage at recency was eliminated by spoken suppression, but unimpaired by mouthed suppression. These results call into question current assumptions about the functional equivalence of acoustic and mouthed input conditions, and support instead a multi-component approach to recency effects [211].

65.7b Long-term memory. In research exploring long-term memory differences for material presented in different input activities, Conway and Gathercole established persistent memory advantages to acoustic over non-acoustic presentation conditions in incidental learning [208], and have shown that vocalization leads to better memory retention than passive listening [214]. In this paper it was also found that writing words read at input does not enhance memory performance. On this basis, they proposed that these modality differences in long-term memory reflect the distinctive nature of acoustic inputs, and effective use of self-generated retrieval cues of one's own voice in accessing representations of vocalised events.

This work is continuing at the University of Lancaster where Conway and Gathercole have been appointed to lectureships.

65.8 Memory for Faces (Valentine)

Face recognition is not only of considerable applied interest in itself, but also provides a good example of a visual object recognition task which can be readily studied in the laboratory.

The model of face recognition being tested is based on the assumption that the similarity between faces can be thought of as distances in a multi-dimensional space. In such a space faces would be normally distributed around the central tendency of the population of faces experienced. One possibility is that faces are encoded as differences from a prototypical face which represents the central tendency. Investigation of this model has centred on the effects of three factors: typicality, inversion and race; the initial results of experimental studies are extremely encouraging [235]. Simulations of neural networks have also been carried out to explore the basis of the prototype extraction process. This work is relevant to studies of concept learning and categorisation as well as face recognition.

The recognition of other-race faces is an important theoretical issue for the model because it provides a possibility of separating predictions of two different versions. A collaborative cross-cultural project with Endo of Hachinuo College, Japan is underway.

A project in collaboration with Bredart of the University of Liege, Belgium, concerns access to semantic information from peoples' names. Much of the recent theoretical progress that has been made in face recognition has resulted from a comparison between recognizing faces and words, but recognition of names has been comparatively neglected. This line of research will be continued by Valentine in Manchester where he has been appointed to a lectureship.

Project 66 - Naturalistic Studies of Human Memory

66.1 Autobiographical Memory

Research on the organization of autobiographical memory and the phenomenal characteristics of remembering has made use of converging operations, where different paradigms and behavioural measurements were employed, ranging from production frequency norms and priming studies, to subjective rating studies and spontaneous recall.

66.2 Organization of Autobiographical Memory (Bekerian, Conway)

Questions about the organization of autobiographical memory have focussed on how information about different experiences is integrated and unified: how are personal experiences organized or understood?

66.2a Bekerian and Conway have argued [250] that autobiographical memory consists of different levels of experience, ranging from molecular (e.g., recollecting the colour of someone's party dress) to molar (e.g., how long the party went on). The relationship between molar and molecular aspects of autobiographical memory was studied using a priming paradigm across a series of seven experimental studies [206]. Results supported the hypothesis that autobiographical memory is hierarchically organized. Very general or molar divisions of time in one's life (e.g., the time I went to secondary school) can serve as reference points around which other

more specific autobiographical memories are organized. These results challenge existing theoretical models that rely on similarity of activities as the basis for autobiographical organization.

66.2b A second series of seven experiments by Conway and Bekerian [207] examined the organization of knowledge about emotions, as it relates to autobiographical memory. People expect to feel certain emotions when they are in certain situations (e.g., expect to feel happy at a wedding); but very little research has been done previously on these situational determinants of emotion. The experiments used production frequency norms and reaction time paradigms. Overall, the results suggested that knowledge about emotions is determined, in part, by knowledge about the situations under which they are expected. The results also identified different classes of situational information that contributed to knowledge of emotions. These classes varied not only in their specificity, but also in their relationship to single, autobiographical memories. It was hypothesized that knowledge about emotions was hierarchical, including semantic, situational and autobiographical information. However, it was also suggested that situational information is independently represented from autobiographical memories, a position which is contrary to other influential memory models.

66.3 Phenomenal Characteristics of Remembering (Bekerian, Dennett)

Research by Bekerian and Dennett has focussed on the vividness of an individual's memory, the quality and the clarity of recall. General issues have been to determine the basis for phenomenally vivid memories, and to assess the relationship between the phenomenal clarity of recall and its accuracy or "truthfulness". This work represents a departure from the more traditional work in autobiographical memory, as it stresses the importance of a multi-disciplinary approach.

66.3a Data from subjective ratings suggested that vivid memories were not, themselves, a homogenous class that could be distinguished from other, less vivid autobiographical memories [266]. The results were interpreted as suggesting that sub-classifications of different types of autobiographical memories should not be made purely on the basis of the phenomenal characteristics of recall.

66.3b Extensive examination of the quality of autobiographical recall was presented in a case study, where an individual was asked to recall a significant and consequential event, his criminal trial (see [264]). In a novel approach to the study of autobiographical memory, discourse analyses were used to determine the relative accuracy of the person's memory and also the qualitative features of memory, such as vividness and expressions of belief. Some significant predictions made from experimental work failed to find support in analyses of accuracy, e.g., personally significant information was not more accurately remembered than non-significant information. It was suggested that accuracy of memory can only be understood in light of the qualitative aspects of recall, which are influenced by the purposive nature of remembering and communicative and pragmatic conventions. This interpretation represents a return to a previous theoretical framework [258] which stresses the importance of the goal of remembering in determining the nature of autobiographical accounts. It is an approach which is finding considerable support in other fields, such as social cognition and discourse analysis.

66.4 Witness Cognition and Memory (Bekerian, Dennett)

Witness memory has developed into a major area of research, focussing primarily on retrieval factors: How do interview techniques influence a witness' accuracy? Which interview techniques are more effective in eliciting

an accurate account? Which effective interview techniques can be applied to real-life situations? The work makes important contributions both to a theoretical understanding of witness memory [258] and to applied issues such as the needs of real-life interviewers.

66.4a Considerable theoretical discussion has been given to the "misleading" effects of post-event information [258]: witnesses can be misled by erroneous information given to them after they have seen an event. The theoretical account has been one which has stressed the importance of the retrieval environment in overcoming misleading effects. Complementary work has been done to determine whether the basis for misleading effects are visua 1-perceptual or verbal-thematic [263]. The results showed that witnesses encouraged to view the event with additional imagery instructions were more affected by misleading information. The results call into question the assumption that imagery will facilitate a witness' recall of an event, and challenge the use of imagery in the interviewing of real witnesses.

66.4b Interest in the effectiveness of interview techniques has been examined, with the intent to use techniques that could, in principle, apply to real-life interviews [201]. A simple manipulation involved asking some witnesses to write their accounts, whilst asking others to give spoken accounts. Systematic differences were found in the amount of correctly recalled information, with spoken accounts being superior.

66.5 Juror Memory and Cognition (Bekerian, Dennett)

The interest here, which developed as a logical extension of the work on witness memory, includes general questions about how jurors come to comprehend and judge evidence in the process of making verdict decisions. There has also been continued interest in examining techniques used for the presentation of evidence in court, with the aim to identify techniques which can improve jurors' comprehension and retention of evidence. Issues of evidential jurisprudence are always considered in this work. Thus, the relationship between the law and cognition is explicitly addressed.

66.5a One study examined how lay-jurors can be helped to understand complex evidence [274]. The study simulated some aspects of courtroom procedures and focussed on presentation techniques that could be used in a judge's final summing-up of evidence. It was found that reinstating the order in which evidence had been originally presented facilitated not only comprehension but also memory for highly complex evidence. The study was part of a contract with the Roskill Fraud Trials Committee. Suggestions were made as to how highly complex evidence might be best presented in fraud cases.

66.5b Another study has looked at the relationship between memory for evidence and verdict decision using simulated jury conditions [294]. Although the dominant explanation of verdict decisions is that they are determined by how well a juror understands and remembers case evidence (that is, a juror who remembers more about the prosecution case will be likely to reach a guilty verdict), the data showed no biases in memory which could usefully discriminate between jurors returning different verdicts. In other words, what a juror remembered could not be used to predict that juror's verdict.

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PERCEPTUAL-MOTOR SKILLS

Project 67 - Timing and Control of Skilled Movement in Normality and Pathology

67.1 Handwriting (Nimmo-Smith, Wing)

Even though we initially acquire skills such as handwriting by direct guidance based on a standard "model", an individual, personal style usually emerges as skill develops. Such between-individual variation is, in the case of handwriting, the basis for forensic determination of authorship of documents. A study of children's acquisition of cursive writing [322] points to the influence of penhold as one source of developing individual differences in letter formation, probably because different grips constrain pen movements in different ways. A second study [323] identifies certain changes in children's writing with their need to write faster as they get older.

At present forensic document examination relies mainly on qualitative aspects of letter formation. But as computer-based automated comparisons become practicable, basic data on quantitative variation will be required. Some of the issues that will require attention are illustrated in an analysis of data collected under an earlier Home Office contract [314]. One significant finding is that higher-level, linguistic factors influence the variability of pen strokes that, in terms of their lower-level movement description, are ostensibly the same. Thus automated comparison of writing samples will need to take account of text content. Other recent research on handwriting at the Unit has focussed on higher-level processes relating to the representation and selection of letterforms. A single-case study [111] provides evidence that different forms of the same letter (allographs) are stored separately. A neurological patient who had suffered a stroke was left with agraphia associated with constructional apraxia. However his writing deficits were selective, affecting lower-case rather than block capitals. This suggests that the storage of letterforms is organised according to letter context rather than being purely alphabetical.

67.2 Hand Positioning (Nimmo-Smith, Wann, Wing)

The fastest means of covering a given distance between two points is to use maximum acceleration followed by maximum deceleration. However, the resulting movement is likely to be abrupt, jerky and hard to control. Thus individual movements in highly-practised skills, such as handwriting, are not generally executed as rapidly as possible. A promising new line of investigation has been the evaluation of the time course of unconstrained movements in terms of a criterion that minimises mean square jerk (which is defined as the rate of change of acceleration). Estimates of jerk are lower for children whose handwriting is rated more highly by their teachers; poorer writers exhibit more jerk [305]. In adults, drawing movements in the production of ellipses are consistent with the minimisation of jerk [310]. The latter study also provided evidence of departures from a relationship between the speed and curvature of movement widely known as the "two-thirds power" law (see also [306]).

67.3 Motor Rehabilitation (Lough, Wing)

Voluntary arm movements often improve after hemiplegia consequent to stroke, and the literature provides several qualitative descriptions of recovery. However kinematic details of the time course of movements and quantitative estimates of recovery curves have not been established. Long-term evaluation of changes in upper

limb function after stroke indicates the value of characterising recovery of voluntary movement (visually-guided hand positioning) in terms of peak angular velocity of the elbow [313]. Clinically, spasticity is often characterised by a postural synergy of flexed shoulder and elbow; however the recovery of elbow function in voluntary movements is uninfluenced by shoulder movement.

67.4 Force (Wing)

Despite the pervasive importance of the use of force (for example, in grasping objects) and the fact that impulsive force development is a basis for rapid, aimed, ballistic movements of the kind that are frequently studied by psychologists, the control of force is a largely neglected topic in research on psychological mechanisms of motor control. A relation between these two aspects of motor control is implied, for example, by the fact that, in parkinsonian bradykinesia, characteristic slowness in carrying out a movement is linked to a reduction in the ability to make abrupt changes in grip force [311]. A new quantitative theory, the parallel force unit model [304], has been formulated. It predicts the expected form of brief force impulses as a summation of a large number of noisy output channels. The theory is of potential importance not only in its own right, but also as a route to understanding relations between speed and accuracy in rapid, aimed movement.

Project 68 - Organization and Development of Skilled Performance

68.1 Reaching (Wing)

Many activities require concurrent execution of two or more psychologically distinct elements. One view holds that low-level coordinative structures link the simultaneous performance of separate actions and that these links are modified as skill advances. A continuing research effort at the Unit has been the demonstration of the existence of such links and of ascertaining their functional nature. The prototypical task that we employ is reaching for objects in the environment. This has two components, transport of the hand towards the object and shaping of the hand into a grasp, that are quite distinct. Indeed it has been suggested that these separable aspects are regulated by two independent visuo-motor channels. However, APU research demonstrates a dependence of mean hand aperture on the transport component [315, 319]. Changes in hand aperture provide a degree of compensation for inaccuracies in the transport component. Preliminary correlational analyses indicate that the hand aperture-transport dependence is predictive or feed-forward in nature and not due to feedback corrections made during movement. As such the dependence represents a control algorithm of potential interest to engineers working in robotics [318] and suggestions have been put forward for the definition of a criterion task for the evaluation of reach and grasp performance of teleoperated manipulator systems [325].

68.2 Timing (Nimmo-Smith, Wann, Wing)

In many skills (including handwriting - [324, 309] the accurate timing of successive movements is critical. A task that allows assessment of the variability of timing is periodic finger tapping of a response key at various predetermined rates. Recently, additional complexity has been introduced into the tasks employed in order to develop an understanding of the coordination of a number of separate response streams [312]. Subjects had

to produce accurately timed intervals by tapping with one hand or by using the two hands in alternation. The latter yields more variable performance. In alternate hand tapping, simulation modelling of the sequences of interresponse times suggests the existence of two internal clocks that interact with one another. This postulate of two "equi-potential" controllers departs from the strictly hierarchical view of motor control often associated with the information processing approach [317].

68.3 Space and Action (Marcel with M. Brouchon, Marseille)

Perceptual-motor space appears to have two major divisions: left and right, and near and far, but the basis of such distinctions remains problematic. Marcel and Brouchon have studied double dissociations between near and far space in visually guided motor tasks in patients with optic ataxia and in normal subjects; results suggest that the most relevant variable is the intentional nature of the task (touching, grasping, throwing, pointing) rather than distinctions related to the object or objective distance. Thus, relative spatial accuracy in peri- and extra¬corporal space can be reversed if patients are enabled to grasp far objects with an extendable pincer or forced to point to near objects. In normal subjects the nature of spatial errors in speeded tasks has been shown to depend on (a) whether the instructions are to grasp, point to, or touch objects, and (b) the strategy of hand utilization necessitated by the mutual proximity of targets; these differences mirror those found in performance in peri- versus extra-corporal space. The major difference between tasks differentiating near and far space appears to be between manipulation and deixis (indication). Preliminary work on hemineglect suggests that this intentional distinction may illuminate divisions in the horizontal plane. While right-parietal/left visual field neglect is observed much more than left-parietal/right neglect, almost all indices of neglect concern peri-corporal space and non-deixic tasks. Interestingly, when given deixic tasks in extra-corporal space, two out of three left parietal patients showed (previously unobserved) right neglect.

68.4 Influence of Intention on Accessibility and Fluency of Action (Marcel with C. Garvie, Rehabilitation Unit, Addenbrooke's Hospital)

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. Marcel has 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 performed had social or personal significance. These findings suggest that motor control is strongly influenced by the nature of the intention.

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THINKING

Project 69 - The Study of Modelling of Cognitive Skills and Expertise

The general framework of this research is based on two main ideas: the notion that high-level cognition calls for the construction of mental models of the states of the world [371], and that the cognitive processes of thinking, reasoning, and imagination can best be understood in computational terms [368, 367, 333, 366].

69.1 Comprehension of Discourse (Anderson, Johnson-Laird)

According to the theory of mental models, discourse can be understood at two levels — one superficial level that is similar in structure to the sentences of the discourse, and one more profound level that is similar in structure to the states of affairs described by the discourse [364, 340]. The meanings of words must provide the information necessary to construct models of the situations that they can be used to describe [369]. This theory predicts that discourse will be harder to understand if the order of the sentences makes it difficult to retrieve the links between co-referential phrases [336]. It also predicts that discourse will be harder to understand if the events that are described are difficult to integrate using general knowledge. The first factor is peculiar to discourse, but the second applies to the interpretation of any domain, e.g. perceived events. It follows that the two factors should have independent effects, and two recent experiments have confirmed this prediction [388].

69.2 Studies of Inferential Processing

69.2a Informal everyday inferences (Anderson, Johnson-Laird). Reasoning in everyday life often occurs in situations in which there is insufficient information from which to derive a valid deduction. If the process depends on the construction of models of the premises and a search for putative conclusions, then we can predict that such a search will be influenced by several variables [370, 389]. Contrary to strict Skinnerian principles, people search more assiduously when they are told that their previous conclusions are wrong — as opposed to being told that their previous conclusions are possibly correct. Ordinary individuals establish putative conclusions, even between quite disparate events, very rapidly [365].

69.2b Deduction (Byrne, Johnson-Laird). The theory that comprehension and reasoning depend on the construction of mental models of the situations described in the discourse [392, 390, 374, 391] has been extended. Five experiments on propositional reasoning, which depend on such connectives as "if", "and", and "or", have shown that the number of situations that a reasoner has to hold in mind determines the difficulty of

making a deduction. This phenomenon was predicted by the theory that reasoning depends on constructing mental models of the situations described by the premises [361, 380], and runs counter to predictions derived from theories which assume that people are equipped with a mental logic containing formal rules of inference. Predictions of the two theories have been compared in two other domains: spatial reasoning, where the difficulty of a deduction was related to the number of different layouts that have to be kept in mind [332]; and reasoning with premises that contain either single quantifiers, such as "only" (four experiments reported in [341], see also [384]), and premises that contain pairs of quantifiers, such as "none" and "all" ([382], three experiments in [342]). In all three domains, the complexity of formal derivations had no relation to the difficulty of the inferential task.

Project 70 - Risk Assessment, Judgement of Causality and Decision Making

70.1 Judgement of Causality (Shanks)

Shanks has investigated the way in which people detect causal relationships, particularly between their own actions and the events caused by them. The processes involved are implicated in many theories in psychopathology, decision¬making, and perception. In this project, a new causality judgement procedure has been developed, but the main concern has been to test a normative theory which proposes that people base their causality judgements on the metric dP, which is the difference between the probability of an outcome given an action [P(0/A)] and the probability of the outcome in the absence of the action [P(0/-A)]. This theory assumes that people maintain subjective representations of these probabilities and take the difference between them as the basis for their causality judgements.

The project has highlighted a wide range of difficulties inherent in this view. For example, it says little about the role of temporal contiguity, yet a series of experiments [356] has shown that as the time interval between the action and outcome increases, judgements of causality decrease. The normative account can only explain this by saying that, as a result of the delay, the action and outcome are no longer perceived together as a pair; the data do not seem to be consistent with this view [355].

A second problem with the normative theory concerns acquisition profiles in causality judgement experiments. As people receive more experience of a causal relationship, their judgements of causality, and their confidence in those judgements, become progressively greater [355]. The normative model has difficulty explaining the details of these learning curves.

The final, and most important, problem for the theory is the demonstration of selectional processes in causality judgement. A cause never occurs in isolation, but in the presence of other potential causal events (the "causal context"). It has been shown [351] that the extent to which a target cause is associated with an outcome depends critically on the extent to which the causal context predicts the outcome, even though this does not alter the normative measure, dP.

In general, the data seem more consistent with an associative model of causality judgement in which an association is formed between the mental representations of the cause and effect. Such a model has been implemented as an OPS-5 production system [385].

70.2 Categorization by Connectionist Networks (Shanks)

Shanks is attempting to determine whether connectionist networks can reproduce the results of a series of experiments [352, 353] on people's ability to deal with novel instances of some category. Learning in the network consists of finding a matrix of weights which will map input patterns (the stimulus to be categorized) onto output patterns (the category). A series of experiments has examined the predictions of this model concerning the way in which the features of an instance become associated with the category. In the experiments, subjects have to diagnose the illness (which constitutes the category) of a series of hypothetical patients on the basis of their symptoms (which constitute the features).

Feature-category associations are formed to the extent that the feature is a good predictor of that category, even though this may affect neither the probability of the category given the feature [P(C/F)] nor the probability of the category in the absence of the feature [P(C/-F)]. It is just such probabilities, according to cue-validity models of categorization, which determine assignment of objects to categories.

For example, in one experiment subjects saw patients with symptoms A and B, who all had disease 1, and a smaller number of other patients with symptoms A and C who all had disease 2. When asked to categorize a new patient with symptoms B and C, the subjects chose disease 2, quite contrary to the base rate of the two illnesses. This phenomenon, which has caused much perplexity in the literature, is readily explained by a connectionist network. In the network, a stronger association is formed between symptom C and disease 2 than between symptom B and disease 1.

The Rescorla-Wagner and Mackintosh theories [352], developed to account for conditioning experiments using animals, are similar to the network model and seem to provide good descriptions of the mechanism responsible for determining the strength of the feature-category associations. The first of these theories is formally equivalent to the delta rule, a widely-used algorithm for adjusting the weights in connectionist networks. Specific predictions from computer-simulations of this theory have been upheld, and so it appears, at present, that the data are consistent with a connectionist model of categorization.

70.3 Classical Conditioning (Levey)

Classical conditioning represents a very simple form of information processing and learning. When studied in human subjects it affords an opportunity to examine the interaction of higher cognitive processes (e.g. decision and planning strategies), with primitive learning mechanisms which lie largely outside conscious awareness and probably function automatically. Several studies (in collaboration with Martin, Institute of Psychiatry, London) based largely on human eyelid conditioning paradigms have suggested that this interaction involves a degree of independence between verbalisable knowledge of the learning task and its actual performance [375, 377, 344]. The classical conditioning technique has also been applied to the modification of preferences. A series of parametric studies has shown that acquisition of preferences for picture materials follows the general principles of simple automatic conditioning [376].

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INTERACTION WITH TECHNOLOGICAL SYSTEMS

Over the course of the last twelve years, through a combination of externally and internally funded effort, the Unit has been building upon its programme of research on a range of issues concerned with the use of computers. Through studying the patterns emerging in people's cognitive behaviour with interactive systems, this area promised benefits both for the development of basic theory and for its application. During the period covered by this particular progress report, progress has been consolidated and extended on issues concerned with expert systems, interactive dialogues, user modelling as well as the psychology of programming and notations in general. The theoretical benefits have started to come through strongly, and the problems of

bridging between laboratory data, theories and the practicalities of systems design are now receiving greater research emphasis. This section will first review our empirical contributions, followed by a summary of the main developments in modelling, a review of achievements and proposals for future work.

Project 71 - Modelling Users of Interactive Devices

71.1 Knowledge Elicitation for Expert Systems (Gammack, Young)

Research on the application of psychological techniques for the elicitation of expert knowledge for incorporation into expert systems, has been done by Gammack, APU's first CASE student, (sponsored by Unilever pic). This PhD [538] focussed on the question of the structure of and relationships between the basic concepts in a technical domain, which is known to be an issue requiring attention early in the process of knowledge elicitation.

The work is based on the argument that existing psychological techniques, developed in the laboratory and intended for use with groups of subjects in toy domains, could be adapted and would prove useful in eliciting knowledge from single experts in domains of serious industrial interest. (The domains used include the selection of appropriate statistical tests for analysing market survey data, and the choice of library sources for seeking technical information.) Early results [453] emphasise the variety of techniques available and their suitability for different kinds of knowledge, and refer to well-established structuring techniques such as multi-dimensional scaling, cluster analysis, and repertory grid, along with a newer technique, "pathfinder analysis", which this work helped to pioneer. Later results go on to stress the convergence between these different techniques and the way they lend themselves to experimental verification [499, 454]. As a contribution to the art of knowledge elicitation, these techniques offer the advantages that: (1) They are quick to use; (2) They include procedures for their own validation; (3) They can be used with single or multiple experts; and (4) They yield graphical representations. They also provide part of the foundation for future tools to aid in knowledge elicitation, which depend upon the expert and the computer system sharing a body of core domain knowledge [486].

Related work [527, 480], has developed the argument that the results of knowledge elicitation should be recorded in one or more "intermediate representations", in contrast to the prevalent practice of going straight "from chat to rules", i.e. of coding information given by the expert directly into a machine-executable form. Among the advantages of using intermediate representations are that: (1) They serve as a record of the elicited knowledge independent of the technology used; (2) They can act as a medium of communication shared by expert and elicitor; (3) They provide a more complete record of the knowledge than can be captured in a machine-executable representation; and (4) They can be used for purposes other than building expert systems. The argument is gradually becoming accepted in the field.

71.2 The Acquisition and Use of Knowledge in Interactive Dialogues (Barnard, Maclean, Wilson)

The Unit's ten year collaboration with IBM drew to a close in 1987. While the early part of this research programme focussed upon the learning of simple interactive tasks by entirely novice users, the latter part concentrated on the learning of dialogues in more complex systems and upon the transition from novice to

more experienced patterns of use. Issues associated with the representation and use of task and system knowledge were the major points of concern.

Through systematically studying the learning of an integrated office system with several techniques, it was observed that the accuracy of performance on different tasks in various system environments progressed with markedly different properties and at different rates. This evidence suggested that it was unhelpful to think of learning in this context as following a unified progression from declarative to proceduralised status. Rather, a repertoire of knowledge-based skills develop at different rates and stabilising at different levels. The very variability of performance in these tasks also has profound implications for the nature, interpretation and development of valid industrial "benchmark" tests of usability [519,543].

This same study also produced striking illustrations of the complex relationships which hold between "knowledge" and "performance". For example, given a choice of methods which take differing amounts of time, there are circumstances in which even experienced users will systematically choose the slower method of achieving their goal [552, 512]. Here the precise pattern of time data can be mathematically modelled as a linear function of the task parameters. However, the method selection data are best modelled by assuming that users manage the complex decision space by relying upon a "simple compensation schema" which biases choice [440]. Likewise, what people can verbalise about systems and tasks also bears a complex relationship to their performance. Verbal descriptions of tasks that accurately characterise how a system works develop in a different way from those that do not accurately characterise how it works. Accurate and inaccurate verbal descriptions also show very different patterns of correlations with performance time and error scores. These data [536, 403], and related data collected in a subsequent experimental study [482], indicate that the modelling and prediction of good performance on the one hand and errors on the other will require concepts that differentiate the roles and functions of ideal and non-ideal knowledge as well as the circumstances under which it is accessed and used. The data also contain a cautionary tale for those relying on single sources of data. Indeed, in such complex tasks understanding relationships among the many possible measures of knowledge and performance is a major concern for the development of theory and practical assessment techniques [522, 521].

71.3 Dialogue Form and Content (Barnard, Conway, MacLean, Wilson)

As interactive systems increase in their capabilities, more flexible dialogue structures and navigational opportunities are being incorporated into system designs. Experiments covered in the last progress report suggested that, although of value, certain forms of flexibility in simple dialogue tasks led to very real costs in initial learning and transfer to more complex tasks. Recent experimental work has extended this kind of result to more complex experimental settings. With tasks involving the same number of dialogue steps, learning and transfer costs can be greater with some forms of multi-tier menus, when compared to a more constrained hierarchical menu structure [402, 534]. The requirements of actually performing this kind of experiment in a realistic way led to the practical development of a user-interface management system specifically for behavioural research, the design and implications of which have also been reported [513, 418].

Another series of studies by Conway, Norris and Bowers concentrated upon the problems of using keyword systems [497]. One of the reasons for difficulty in the effective use of such systems is that there is little

normative agreement between subjects as to which keywords are most likely to prove effective in accessing targeted information: this is even the case when the keyword system is made up of semantic categories and subjects are informed and given feedback about the structure of the system. It seems that subjects will only attempt one or two normative keyword responses and if these fail to access the target information, then subjects tend to generate personal idiosyncratic keywords which, of course, do not map on to the structure of any keyword system.

71.4 Mental Models in Performance and Design (Barnard, Duff, Young)

It has often been argued that learning complex tasks should be facilitated by the prior provision of an adequate mental model of the device. The empirical evidence on the point has remained ambiguous for some time. A series of experiments by Duff has systematically compared the effects of different forms of prior knowledge about task procedures and about the underlying device model. Relative to exploratory learning and presentation of procedural instructions, prior presentation of task relevant device knowledge can and does facilitate retention and subsequent problem-solving performance. Furthermore, it does so, with slightly different properties, where the task demands are for strict sequence learning or for free order selection of command operations [498].

Earlier theoretical work on mental models of interactive devices (Young 1981, 1983) has also been applied directly to illustrate its application to a practical design problem. The basic work suggested that a "task-action mapping" could perhaps provide a useful basis for the design of interactive systems. In order to explore this hypothesis, Young and Harris [528] undertook the exercise of designing a program for editing viewdata structures, based upon a task-action mapping analysis. The exercise proved successful, with the resulting editor exhibiting an unusual structure that provides a close meshing between the user's moment-to-moment goals and the actions offered by the system.

71.5 Formalisable Models of User Knowledge (T Green)

The user's knowledge of an interactive device was modelled by Payne and Green [423] in terms of a feature-grammar, TAG (this work was started while the authors were at SAPU). TAG represents a 'competence' model of the user of an artefact, that is, it emphasizes the user's knowledge of how-to-do-it rather than the user's behaviour or the user's conceptual model of the device. The novelty of TAG is that it captures the user's ability to generalise from partial knowledge, at least in the case of 'consistent' user interfaces where similar methods are used for achieving similar goals. It is trivially obvious that novices do not learn how to do bold face printing and then learn entirely separately how to do italics printing; they can generalise. Unlike prior research on the ability to generalise, TAG provides a model which predicts exactly what forms of consistency can be exploited by the learner meeting a user interface language. It was shown that TAG correctly predicted which of a number of artificial languages would be easiest to learn, even though that language was not the one whose context-free phrase-structure grammar contained the fewest rules [424]. The status of 'competence' theories of user knowledge against 'process' theories was explored, and a number of new metrics over grammars were suggested [458].

This research on TAG was partially supported by an ESPRIT contract to develop a 'Cognitive Simulator'. In this context, formal descriptions of life-size examples were developed; it is important that the usability of HCI

models be assessed against real cases. TAG is now one of the few formal methods in HCI to have been applied to a number of life-size examples; moreover, by extracting the common features from these descriptions we have obtained a model of 'cross-applicational consistency', the degree to which knowing one applications program may help with learning another [461].

Green has developed a Prolog program which interprets a TAG description, so that given a statement of the user's goal the program will state how to achieve it in a given system. The original purpose was to help check the large grammars that are being developed, but it has subsequently emerged that an executable system also helps to predict some classes of errors, notably the 'description errors' in which users apply a correct method to an inappropriate object (e.g. trying to put a circle into italics when using a drawing program).

71.6 The Psychology of Programming (Gilmore, T Green)

Writing computer programs is a difficult real-life skill of increasing importance, bringing together many of the concerns of applied cognitive psychology. Theories of programming assume that individual fragments of written notation are conceptualised in larger units, which in the case of program notations have become known as 'programming plans'. These plans putatively express the conceptual role of each notational fragment. Strong versions of this theory assert that all programming expertise can be accounted for in plan terms; Green has criticised traditional computer science views in the light of cognitive theory and experiment, and explained why the so-called methodologies work when they work [502, 550]. Since evidence for the psychological reality of this theoretical construct was very limited, it was timely to conduct an empirical test. Gilmore and Green hypothesised that the comprehension of the plan component of programs would be increased if all parts of a single plan were highlighted together, but that comprehension of the control component would be unaffected by plan highlighting: and vice versa when the control structure was highlighted. This was indeed the case for one programming language (Pascal), showing that mental representations of program structure were notably multiple in nature, including at least plan and control structures. In the second language (Basic) the data suggested the control flow was the main form of mental representation, and that plan structures were a poor model of programmers' knowledge. [501, 410].

Adherents of 'programming plans' have also claimed that program development proceeds in units of one plan at a time. This claim was also put to the test. Expert professional programmers were closely studied solving problems in one of their speciality languages. Four languages were compared, and full details of keystrokes were recorded. Results showed that the local tactics depended on the language: Pascal programmers moved to and fro in the code making insertions here and there, significantly more so than users of other languages; Basic programmers in particular tended to run off long streams of code without jumping around. While plan structures appeared to play a role in the sequence of program development the behaviour was also apparently determined by details of the notational structure (notably its resistance to local change, termed by us 'viscosity') and the ease of parsing the notation back into plan structures (termed by us the 'role-expressiveness') [503, 504]. A theoretical analysis has been developed, the 'cognitive dimensions of notations', which will be described below.

Conway and Kahney have also explored programmers' behaviour, this time in a transfer of learning procedure where programmers attempted to write a recursive procedure in an AIM language [496]. The principle finding

was that transfer of learning was facilitated only when information about the formal definition of recursion and a mapping relation were explicitly provided. They concluded that current models of learning could not account for these findings and that educational practice might benefit from the fact that formal definitions or illustrative examples alone do not facilitate learning.

71.7 Towards Approximate Models of Cognitive Activity (Barnard, A Green, Maclean, Wilson)

Theoretical advance in the domain of human-computer interaction must have the scope to encompass a broad range of system and task characteristics, as well as complex and often strategic behaviour on the part of the user. It must also furnish a means of communicating or delivering theoretical analyses into the processes of system design. One recent development has been to make empirically motivated theoretical principles explicit and deliver them through an expert system which constructs descriptive models of cognitive activity in complex tasks. The flexibility and power of AI technologies allow many of the problems associated with over-simple "design guidelines" to be circumvented [520]. Based upon Barnard's interacting cognitive subsystems framework [249], a new form of cognitive task analysis has been developed to generate an approximation over the operation of a distributed network of cognitive resources. This analysis holds that overt behaviour will be a complex function of process configurations, the procedural knowledge they embody, memory records accessed and the way in which the operation of distributed resources is co-ordinated and controlled. From this point of departure several of the earlier series of experiments were analysed to yield explicit functions inter-relating these factors [531,441].

These theoretical functions were then implemented in an expert system which incorporates the two additional kinds of rule required to (1) map input descriptions of systems, tasks and users onto the theoretical approximations; and (2) generate behavioural characterisations from those approximations. The initial knowledge bases [535, 404, 405] illustrated how a limited range of principles could work in simple tasks and how they could generalise from one form of dialogue or task (eg command names) to others (eg iconic dialogues). As well as extending basic principles, subsequent knowledge bases have explored how to build families of inter-related models covering a range of expertise levels and for different phases of extended tasks. The use of an automated modelling system based upon expert system technology provides a direct means of delivering psychological knowledge into the design domain without requiring the applier to be an expert in the modelling technique, or even an expert interpreter of the subtleties of empirical evidence. However, the use of this modelling technique is not restricted to the delivery of an "applications" theory for human-computer interaction. As a cognitive modelling methodology, it lies in between classic verbally formulated theory and full blown AI simulations. In order for the modelling system to run, all assumptions and the logical relations asserted within a theory must be fully explicit and mapped to relevant task conditions. By being explicit, it avoids some of the problems associated with under-defining the formulation of theory in verbal terms. By representing knowledge in terms of approximations, it avoids the requirements in full blown AI simulations of specifying task relevant knowledge in its full extent. As such, the modelling technique is now at a stage where work in an applied domain can feed back to laboratory paradigms and outwards to other applied problems. Indeed, plans have been laid to develop and apply these techniques to the analysis of cognition and affect in laboratory and clinical settings (see proposals for Project 79).

71.8 Towards Programmable User Models (Young)

Another major strategy for representing and delivering psychological theory in the context of human-computer interaction has been pursued by Young and his colleagues. Since 1986 this has been done in the context of an Alvey project, in collaboration with Logica Cambridge Ltd and STC Technology Ltd, on the topic of "programmable user models" (PUMs). PUMs explore a novel approach to the problem of how to build predictive models of complex human behaviour which are accessible to professionals (in this case interface designers) who probably do not have a specialised training in psychology. A PUM is a constrained cognitive architecture that can be programmed (e.g. by an interface designer) to simulate an hypothetical user performing some range of tasks with a proposed interface. PUMs are intended as an effective way of conveying psychological considerations to the designer, by virtue of involving him/her in the actual process of building the model and making the predictive evaluations based upon it. The designer is thus in a position to see where the predictions come from and what factors they depend upon.

Following the effort spent clarifying notions of PUMs, much of the project was devoted to the investigation and assessment of different possible approaches to the integrated cognitive modelling of users. The favoured approach emerging from this work is inspired primarily by the SOAR architecture of Laird, Newell and Rosenbloom (of which more below). Later work on the project consisted of identifying the cognitive characteristics of the user most crucial for modelling human-computer interaction, and of preliminary investigations into ways of making SOAR reflect those characteristics. Although it will still be several years before there exists a running PUM, the industrial partners find that thinking about interface design problems in PUM's terms seems to help designers conceptualise the interface from the user's point of view. One interpretation of this (unexpectedly) early piece of technology transfer is that, while designers are frequently urged to "consider the interface from the user's viewpoint", such advice falls short of helping the designer know what actually to do. But to pose the question for a PUM "What 'program' must someone execute in order to use the interface?" provides the designer with a concrete and practical means for mentally stepping into the user's shoes.

Overview papers from the project serve, firstly, to explain its aims and methods [439], and secondly to propose a multi-dimensional classification of user models within which PUMs can be related to other approaches [516]. The technical papers from the project so far deal with particular aspects of human-computer interaction examined closely from the PUM viewpoint. Consider, for example, the situation facing a user sitting at a keyboard, who knows what he/she want to do, but not what steps to take to accomplish it. This kind of problem solving falls under the heading of "planning", and the project has examined the nature of planning in the HCI context [529, 517]. In contrast to the concerns of planning as studied in Artificial Intelligence, users produce just partial plans, they interleave planning with execution, and they plan opportunistically. A planning structure that would exhibit those characteristics has been proposed. Another example concerns the representation of procedural knowledge. In answer to the question "What does a user know, who knows how to do some task?", it is conventional to offer a procedure, i.e. a fragment of a program for performing that task. But such a purely procedural representation states both too little and too much. It states too little in the sense that it fails to explain how people do many things with their procedural knowledge other than just execute it. It

states too much in that it severely overestimates the "knowledge content", i.e. the number of different things that have to be remembered in order to do the task. An account of procedural knowledge based upon multiple mutually-supporting representations resolves these dilemmas [530].

71.9 Towards a Theory of Notations (T Green, Simon, Young)

The instruction set for an interactive computer application (such as a spreadsheet or a word processor) can be viewed as an 'interaction language'. Research on user's knowledge of the interaction language and on the psychology of programming has led towards the beginnings of a more general theory of notations. It is known that in many creative situations, such as designing a drawing or a program, the preferred style of interaction resembles 'opportunistic planning'. This is a type of AI-derived planning, characterised by a control structure which allows the planner to develop any goal at any moment and to switch abruptly from developing a high-level goal to a low-level one and back, and allowing the actor to be driven by data and by circumstances as well as by lookahead [529]. It is possible to list, in abstract terms, many attributes of notations and to show how these relate to opportunistic planning as a form of generalised action theory. For instance, the actor needs the how-to-do-it knowledge described by TAG, but also needs to be able to parse the partly-created text into the appropriate mental representations. Certain information structures would increase the role-expressiveness, others would decrease it. Much of the work performed at SAPU has been accommodated in the same framework, as well as results from other workers. The framework has been applied successfully in industrial contexts [457].

Such a framework has been described by Green [551] as giving 'cognitive dimensions' of notations, in the sense of physicists' use of fundamental, orthogonal, dimensions. Some, including consistency and role-expressiveness, have been derived from the work described above; others emerged as soon as the framework was articulated. An example is the notion of 'viscosity', the work required to make a small change to a text structure. Still others, such as 'trail-following' and the problems of asymmetric pointers, derive from work performed while Green was at SAPU. Perhaps the most important aspect of this framework is that it enables a rational statement about the environment in which a notation is used. What is important is not that a notation has particular features, but that the notational structure and the surrounding environment act together in supporting user interaction. One task for the future is to enumerate some of the techniques by which environments can alleviate or complement the particularities of the notations.

71.10 Confronting the Problems of Scope and Applicability (Barnard, Simon, Whittington, Young)

The application of cognitive models to the phenomena of human-computer interaction has frequently been criticised because most models tend to be of strictly limited scope and also tend to lag well behind commercial developments in interface design. Although cumulative scientific experimentation is undeniably important, it tends to emphasise the accuracy of model predictions at the expense of their scope and applicability. One proposal to redress the balance is to encapsulate a systematically sampled range of behavioural phenomena in idealised scenarios. These are not unlike test sentences in linguistics. By "test driving" a range of models against such scenarios in a form of theoretical matrix, it is possible rapidly to extract common properties of different models, and to capitalise on just those properties most likely to lead to enhancements of scope and

applicability [438, 547]. The three approaches outlined above (TAG, SOAR and Interacting cognitive subsystems) were considered along with other approaches in an early theoretical matrix.

Further Consolidation, Reviews and General Dissemination

In addition to developing new lines of empirical enquiry, and firming up theoretical approaches, older work has been consolidated, with significant effort directed at wider dissemination of research results.

Some further work [526] has been done extending earlier research into the human interface aspects of expert systems, the argument being that interacting with systems which are "quasi-intelligent" rather than merely complex poses novel issues. Some of these issues are akin to those that arise during interaction between people, such as the respective social roles of the two participants.

There have been further publications on the learning of command-argument structures [417], and the learning of extended task sequences [511]. In addition, all the work on command names has been collated and synthesised in a book chapter for the research community [445]; and a complete review of the whole command name field presented in a definitive handbook of human-computer interaction [533, 444]. Alternative approaches to task analysis, including those originating at APU, have also been reviewed and structured [462, 544], and more general overview papers have appeared (Shallice, 1982, [411]).

The potential application of a range of cognitive techniques provided input to an ESPRIT project concerning human factors tooling [495]. The work outlined earlier on TAG also contributed a number of internal reports to this project. The nature of evidence and theories has also been presented and discussed in book chapters directed at human factors [443, 532] and software engineers [442]. A chapter reviewing information-processing models in HCI was also prepared as a contribution to the definition of European research objectives arising out of the FAST programme [457].

In the case of AI, a tutorial introduction has been written [560], based on one of a series of videotaped lectures, explaining how "production systems", originally introduced into Cognitive Psychology and Artificial Intelligence as a technique for modelling human problem solving, have properties that enable them to be used as the core of expert system technology. Other previous work by Young consists of models of cognitive skill cast in the form of a "production system". Such models raise problems as to how they are to be evaluated appropriately, since data from a subject are used in deciding what model to assemble, and conventional techniques such as split-halves are not always applicable. A paper [515] based on work in a PhD thesis by Tony Priest (then a graduate student at the Open University, supervised by Young) proposes and compares a number of methods for performing this kind of evaluation.

The Unit has also been intimately involved with the development of European associations in the area of HCI. Green has been associated with a biennial series of European meetings on cognitive ergonomics since their inception in 1981, and has co-edited books based on the meetings [399, 401]; at the 1986 meeting it was agreed to form a formal constituted organisation, the European Association for Cognitive Ergonomics, and Green joined the founding committee. The first conference held by the new association took place in Cambridge in 1988. Green is also associated with the Psychology of Programming Interest Group, which is co-operating with its French counterpart in editing a book of invited contributions on the psychology of

programming [400]. Similarly, Young is coordinating the European interest in SOAR. Members of the Unit have also delivered invited keynote addresses at European meetings on these topics [456].

This is also an appropriate place to note an Alvey contract held jointly between SAPU (Clegg) and APU (Green), aimed at presenting the techniques of both HCI and organisational psychology in a more accessible form. This project delivered a small book on "How to Evaluate your company's new technology" [398] intended for non-specialist readers.

71.11 Rank Xerox EuroPARC

In 1987 Rank Xerox opened its Cambridge EuroPARC, a laboratory for research in human-computer interaction with strong links to its famous parent laboratory Xerox PARC (Palo Alto Research Center). APU staff collaborated closely with Xerox over the setting-up of EuroPARC, and indeed the presence of APU is known to be one of the considerations influencing the choice of Cambridge as a site for the laboratory.

This close collaboration has continued, with a previous member of APU staff (A MacLean) moving to employment at EuroPARC. T R G Green was seconded there for two years, and Young is acting as a consultant, whilst others (P J Barnard, R Patterson) are involved in various kinds of informal research collaboration. EuroPARC are also the industrial sponsor for an MRC Partnership Award research studentship (E Churchill).

An early piece of collaboration between APU and EuroPARC covered in earlier section concerns the re-analysis and modelling of data from the APU/IBM project on users' preferences between two possible methods for accomplishing a task [440]. More recent collaborative work marks the beginning of what is intended to be a fairly long-term investigation and development of "Design Rationale" [419]. The observation behind this work is that when something is designed (say, the user interface to an interactive software system), typically the only thing preserved from the process of design is the designed object itself, in this case the interface. What is lost is the exploration of alternative options, and the web of argumentation and analysis that justifies the final design. Design rationale aims to capture those missing aspects. It is of considerable psychological relevance, as many of the arguments supporting design decisions that affect usability make appeal to considerations of the user, such as partial models of the user or the user's mental model of the system.

Green's framework on cognitive dimensions of notations, described earlier, requires considering a wide range of exemplars and environments. His secondment to EuroPARC enabled him to become conversant with the state of the art in visual programming, object-oriented programming, and program support environments. A short review of recent developments and some of the unanswered psychological questions they raise can be found in [400].

Project 72 - Cognitive Demands of Technical Communications

The value of studying technical communication, apart from any practical applications, is that people working with these materials recruit a wide range of cognitive processes in addition to those commonly thought of as "reading" and "writing". The project objective is a better understanding of the determinants of people's strategic communication choices. Readers choose what, when and how to read. Authors decide what information to provide, in which representational forms, with what sequences and links among items. One way

of enhancing our understanding of these processes is to examine how information design influences people's communication choices. This is evident in the converging approaches adopted for the project which seek to determine on the one hand, the way cognitive processes are recruited when people design written materials, and on the other hand the way readers' performance is influenced by design decisions within, three disparate domains of technical information (electronic documents, instructions and questions, numerical information).

72.1 Creating Technical Communications (Hull, Lickorish, Wright)

Studies of writing processes enable comparisons between reading and writing strategies. They also enable sources of communication difficulty to be distinguished. Possible sources include lack of knowledge (e.g. about design options or readers' information needs) and inappropriate strategic choices (e.g. in the selection of representational forms). Our research suggests that both factors are implicated in the problems writers experience. We have found that adults' written instructions are frequently under-informative. The lack of information is apparently 'deliberate' because these writers can modulate their omissions as a function of the contextual support available to those following the instructions [432]. Such production problems might not be serious if people applied adequate revision skills to their texts. However, revision processes were found to be influenced by linguistic factors (e.g. verb form) which could differ from the factors (e.g. clause location) which influenced readers' comprehension [463]. Subsequent data suggested that revision deficiencies were not adequately remedied by advice given as guidelines.

We have examined design issues relating to information for helping people find their way inside modern complex buildings. Our experimental studies involved the use of both maps and wall signs in a hospital outpatient's department, and our data highlighted the importance of empirical procedures as part of the design process for information of this kind [436]. We discovered a discrepancy between the category of navigation information which enhanced users' satisfaction (maps) and that which yielded faster performance (wall signs) [433]. This discrepancy illustrates the risks inherent in too simple a notion of the reader's "task" when people interact with technical materials.

A range of techniques for text evaluation have been compared and their role in the design process has been discussed [464]. We have outlined the contribution of cognitive skills analysis to the improvement of a wide range of technical communications, and also the nature of the research effort needed in this area [466]. This framework has been contrasted with other approaches to technical writing, for example that represented by the Plain Language movements in Europe and North America. We have responded to numerous requests to relate the research literature on how readers read technical materials, to the needs of specific groups of writers - e.g. educators [426], technical writers in industry [471] and computer documentation [469, 472]. In illustrating that written information is important in many jobs, we emphasized that contemporary functional literacy must include the skills for designing the wide range of technical communications needed in the work place [427].

72.2 Electronic Documents (Lickorish, Stark, Wright)

To take advantage of the large storage capacities offered by media such as optical disks and CD ROMs, new information structures are being devised that exploit functionality not available with paper-based displays. Readers are offered alternative organisations of the same content (e.g. chronological/topical) and can move

rapidly to different parts of the information space. Such documents are called hypertexts when the content is visual and predominantly static, and hypermedia when they involve several modalities and dynamic visual displays. These forms of communication raise many issues about readers' abilities to find and integrate information. Although these cognitive issues are not new, electronic documents are an important research tool because they offer an environment in which readers' strategies, particularly those relating to information seeking, can be monitored unobtrusively.

Contemporary reading theories do not explain why people choose not to read material which is available to them - e.g. clearly legible on the screen. We have outlined a model summarising the determinants of readers' choices about not reading and have pointed out that novel forms of discourse, such as hypertexts, challenge our understanding of many reading strategies [472]. In particular we have emphasized the relation between the content structure (e.g. hierarchical or modular) and the way readers will wish to move about within the text [478]. The authors of electronic documents have many more design options than do the authors of printed texts. We have articulated the constituents of this enlarged design space in order to be able to integrate potentially conflicting data from the many case-studies of hypertexts being reported in the literature [428].

Our experimental studies of readers moving through electronic texts have shown that alternative navigation systems differ in their cognitive demands, as indicated by readers' use of memory aids such as notetaking [523].

An involvement with "electronic journals" led to our examining the problems facing readers of lengthy electronic texts [467]. People had particular difficulty remembering where they had read something previously. Further studies showed that spatial cues were more effective retrieval aids than colour cues because of their sequencing properties [425, 434]. Our data from a small international survey showed that behavioural researchers make considerable use of electronic documents both at work and at home [474].

72.3 Instructions and Questions (Hull, Wilkins, Wright)

Written instructions allow direct exploration of comprehension processes, especially the mental representations that readers create when they plan and carry out actions on the basis of what they read. The important issues concern on the one hand the extent to which readers exploit the optionality they have in forming these representations so that remembering and manipulating the information can be done easily, and on the other hand the extent to which writers giving instructions understand their readers' information needs. Communicating the knowledge gained about how technical materials are read to those who are professional writers and information designers is one way of trying to meet writers' communication needs.

We have demonstrated differences in readers' representation of the information in negative conditionals (unless, if not) for contexts where the conditionals have a logical equivalence [430]. Subsequently we showed that the patterns of performance observed across a range of syntactic forms resulted from the way readers linked the negative element to other information in the representations that they created [431]. It appears that readers do not spontaneously exploit the optionality they have in choosing which representations to use, but are heavily influenced by the surface characteristics of the written information. This enhanced understanding of readers' representations of verbal instructions has been related to the design of written procedures [476]. We

have also responded to requests to apply our earlier research on questions to the design of business forms and the design of forms for clinical trials in medical research [477].

Instructions for the operation of domestic electrical appliances can place subtle cognitive demands upon users; and users' failure to meet these demands can be dangerous. Our preliminary investigation of the task of wiring an electric plug have brought to light some of the ways in which design can guide effective usage [510].

72.4 Numerical Information (Hull, Lickerish, Wright)

Numerical information in the form of tables and graphs is a common component of technical materials and one that allows detailed exploration of readers' strategies for information-seeking. When numeric data can be accessed interactively, as in an electronic document, this permits examination of readers' metacognitive processes relating to information integration - i.e. their choices of representational forms when engaged in making comparisons and decisions on the basis of the information displayed. The research objectives are to ascertain how information design influences cognitive performance, and whether people are sufficiently aware of these design consequences to select appropriate display formats. Such awareness may be a precondition for successfully communicating quantitative numerical information.

We have identified ways of redesigning the numerical information presented in complex fraud trials, so as to make it more comprehensible to jurors [546, 435]. Current studies of people using simple graphs show that discrepancies can arise between the display formats yielding faster performance and those which users prefer. This suggests that in the multistage process of making comparisons within graphical data, different stages are influenced by different design factors.

Project 73 - Study and Modelling of Transport System Users

The behaviour of transport system users has been actively researched at the Unit since its inception. Over that time the Unit has made a unique contribution to this field and its output has strongly influenced the way in which this research is organised elsewhere.

An attempt has been made to produce a programme of research which spans a range of perceptual and cognitive issues, both theoretical and applied, involved in the driving task. These issues concentrate on the acquisition and organisation of skilled behaviour and decision making. Five areas of current research are described below, all of which are to some extent supported by external funds. In addition to this work, and his recent appointment as Professor of Traffic Science at Groningen, Brown continues to act in an advisory capacity to international, national and local government/public bodies concerned with transportation issues.

73.1 Individual Differences and Components of Driving Skill (Duncan, Brown, P Williams)

Using an instrumented car driven in normal traffic, Duncan, Williams and Brown have developed procedures for on-the-road assessment of multiple driving skills. The project, which was externally funded by a research grant to Duncan and Brown from the Transport and Road Research Laboratory (March 1986 - March 1988), aimed to supplement the limited information that can be obtained from global measures of driving proficiency, especially accident rate [422, 491]. Skills assessed include aspects of car control, scanning, anticipation and setting

safety margins. Studies have dealt with the effects of experience, the nature of individual differences, and dual task interference.

Studies of experience [408] have compared normal, experienced motorists with both novices and acknowledged experts. In car control experienced motorists resemble experts, while novices are poorer. In scanning, anticipation and safety margins, however, it is the experienced drivers who perform poorly. The skills which apparently deteriorate with experience are those whose failure is rarely punished by immediate adverse consequences. Thus experience by no means guarantees driving expertise, suggesting there might be merit in periodic retraining or retesting. More theoretically, behavioural sequences learned under tuition may later be unstable if they are not obviously linked to general goals [12, 452], including accident avoidance.

Studies of individual differences [409] have dealt with the balance between specific skills and general characteristics that might make one person a "better" or "worse" driver than another. In experienced motorists the finding is that specific skills dominate. Reliabilities within an individual are high, but intercorrelations between skills are uniformly low. It seems that after practice the quality of skilled performance depends almost entirely on very specific learning. Thus individual differences do not reflect any finite set of "abilities". In practical terms, there seems little promise in selection tests given before learning this complex skill.

A dual task study produced results of particular theoretical significance [409]. The research assessed changes in performance across component skills induced by a secondary task chosen to be demanding but to share little obvious content with driving. Performance decrements were modest and, across component skills, the profile of decrements agreed well with a profile of (similarly modest) correlations with "general intelligence" or g. The findings are linked elsewhere in the report to Duncan's wider work on executive functions. It is well known that practice reduces both dual task interference and correlations with g. These results suggest that both changes reflect the same diminishing role of general executive functions as specific skills develop. In support of this view, we have found that head injury patients with clear signs of executive dysfunction show little impairment in driving skills.

73.2 Estimating Time-to-Coincidence/Collision (Groeger, Brown, P Williams/Grande)

Deciding how long it will take to reach a distant object towards which one is travelling is an important component of several driving tasks. Early applied work by Brown [494] showed, in the context of indirect vision devices, that restricting the visual field impairs estimates of when a target object will be reached, usually resulting in 'undershooting'. This research was followed up by Groeger and Brown [506, 414] who showed that subjects' judgements of where they were in relation to an object could be "shifted" by presenting veridical, or non-veridical, auditory speed information and visual information simultaneously.

73.3 Risk Assessment and Decision Making (Groeger, Brown, Chapman)

A relatively high proportion (ca 25%) of road accidents are attributable to mismatches between road system demands and drivers' responses [537]. In a subsequent series of papers [487, 449, 548, 396, 413, 397, 415, 412, 460] Brown and

Groeger have attributed such mismatches to inadequacies in drivers' perception of hazard in the traffic scene and their assessment of their own ability to deal safely with that hazard. However, most research on

"subjective risk" has confounded these two variables, thus preventing its findings being translated into effective accident countermeasures [449].

73.4 The Role of Feedback in Developing Driving Skill (Groeger, Brown, Grande)

The process of learning to drive and the utility of driver training programmes have been discussed in recent papers by Brown and Groeger [446, 451, 452], and inadequacies in the training and long term support of novice drivers have been adduced as contributory factors in the accidents of inexperienced drivers. The central role of knowledge of results in honing performance of skills other than driving has long been accepted, and its role in the driving task should be investigated.

Generally, skills differ in the source (i.e. task-intrinsic/task extrinsic) and predictability of feedback. Not all goals and events when driving alone, for instance, are accompanied by feedback on the success of performance, whereas levels of feedback are obviously high when a person is learning to drive, with the driving instructor being the primary source. When the learner driver later comes to drive without supervision, the extent of extrinsic feedback is greatly diminished, and inability to rely on task-intrinsic feedback may lead to deterioration of skill and contribute to an increased likelihood of accident [452].

73.5 Errors in Performance (Groeger, Brown)

Groeger and Brown have highlighted the interpretation of errors as a prime contributory factor in the understanding of skill organisation and development [507, 397, 415, 412]. The lack of reliable information on driver error in the behavioural antecedents of road accidents is a major failing of routine police reports (STATS 19). It is ethically inadmissible to provoke most of the more interesting and informative errors, for experimental purposes, in road and traffic studies. Yet 'safe' laboratory studies often fail to capture, or simulate validly, the essential characteristics of complex driving tasks.

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VISION

Project 74 - Computational Modelling of Visual Perception

Visual Psychophysics (Watt)

This has comprised work in four main areas:

74.1 Shape Perception

Investigations to discover something of the nature of 2D shape measurement and representation used in human vision produced several findings of note. First, corners and intersections of edges and lines have a priority in visual processing and effectively delimit the spatial extent of integration for smooth shapes even when the smooth line extends across an intersection [588]. Second, the nature of the integration process has also been established [594]. Finally, the limitations on precision have been explored and related to theoretical concepts [607].

74.2 Eccentricity and Peripheral Vision

In a separate enterprise, and in collaboration with Hess and Pointer of the Physiological Laboratory, University of Cambridge, the differences between foveal and peripheral vision have been quantified [573]. There is little evidence for any significant qualitative difference, except that positional uncertainty is very high beyond the central degree or so of vision.

74.3 Time Course of Vision

The most important development concerns the time course of the evolving visual percept. An extensive series of experiments measured the effective spatial scale or resolution of the visual system as a function of time after stimulus presentation [590, 617]. Two distinct functions were obtained. For texture and statistical information there is hardly any effect of exposure duration over and above that anticipated because of the increased signal/noise ratio of the stimulus. For geometric and spatial tasks, on the other hand, the effective spatial scale of the visual system scans from a very coarse level of resolution to increasingly fine degrees in a direct reciprocal relationship with time. The effect lasts for one or two seconds and under some circumstances considerably longer. This work has been related both to a theoretical model of human vision (see below) and also to the various phenomena of visual attention [561]. In particular it has been suggested that many of the "search-light" type of effects can be related to this time course. Whether this is generally true remains to be seen.

74.4 Visual Theory

A major product of Watt's time at the APU was the development of theoretical insight into human vision. His book [561] is a statement of many of the important issues in understanding vision. Its claim is that three different sources of knowledge about human vision, psychophysical, computational theoretic, and cognitive experimental, can be combined to give a single coherent picture of the human visual system as a dynamic process producing refinable, hierarchical representations of the optical image. A mechanism is proposed and the way in which the mechanism could account for many phenomena of visual attention is described.

The essence of the theory is that the computation of spatial position within a metrical framework requires iterative parallel processing and is time consuming. Psychophysical research has identified the mechanisms whereby the effects of this slow process can be alleviated, and the cognitive research can be understood as giving details of how the process can be programmed and controlled.

Project 75 - Visual Discomfort and Environmental Design

A theory of visual discomfort has been developed by Wilkins which can account for the complaints of eye-strain and headache common in the modern office environment. According to the theory outlined in the last progress report but reviewed more recently [596], at least two aspects of particular retinal images (pulsation and "stripes") make the neural computation involved in vision unnecessarily complex, with visual discomfort as a consequence.

75.1 Pulsation of Light (Craven, Neary, Wilkins)

The light from a fluorescent lamp and from a visual display unit (VDU) pulsates at a high frequency. Pulsation of light affects the control of eye movements [621, 210, 597] and accommodation [576] even at high frequencies when the light appears steady. Contours lit briefly during a saccade are not suppressed in the ordinary way but are perceptually confused with those lit afterwards, which may be one reason why corrective saccades are increased in number [577].

Rapid pulsation of light interferes with accommodation [576] and causes headaches and eye-strain. A double-blind study compared conventional fluorescent lighting with that from a new high-frequency circuit that avoids the typical 100-per-second pulsations. The steady lighting was associated with less than half the episodes of headaches and eye-strain [619, 600].

Watts and Wilkins have shown that a substantial proportion of patients with agoraphobia report that fluorescent lighting precipitates their panic attacks [595]. When agoraphobic patients were tested under double-blind conditions, heart rate was higher under conventional pulsating fluorescent lighting than under the high-frequency form [572]. The implications of these findings are far-reaching. Fluorescent lighting is ubiquitous in public places, and if it helps to provoke panic attacks, one possible major factor in agoraphobia has been discovered.

75.2 "Stripes" (Watt, Wilkins)

The visual system seeks to group the detail in the visual image using information in the mid-range spatial frequencies [561]. This grouping becomes computationally complex when the mid-range frequency components are similar and therefore ambiguous with respect to their position. According to the theory of visual discomfort [627], this is why regular geometric patterns of stripes with specific spatial characteristics can provoke eye-strain. The neurological mechanisms responsible for the visual discomfort resemble those that underlie photosensitive epilepsy in so far as they involve an excess of physiological excitation [611, 612]. They differ in that the synchronization of that excitation at a cortical level is necessary for epileptogenesis but not for discomfort [598, 626].

The successive lines of text resemble a pattern of stripes with epileptogenic properties, and this is one reason why reading can provoke seizures, eye-strain and headaches (Wilkins and Nimmo-Smith, 1984, [614, 602]). Some texts are more striped than others, and although this is difficult to discern from the page, it is immediately evident after spatial filtering.

Project 76 - Visual Aspects of Epilepsy and Other Diseases

76.1 Epilepsy (Wilkins)

About 4% of patients with epilepsy are liable to visually-induced seizures. The visual stimulation responsible includes both flickering light and stationary steadily-illuminated patterns, usually of stripes. The seizures start in the visual cortex of one cerebral hemisphere or both hemispheres independently [609]. The seizures occur when normal physiological excitation involves more than a critical cortical area, particularly when the excitation is rhythmic [564].

Studies of pattern sensitivity during the course of therapy with the anticonvulsant drug, sodium valproate, have shown that the drug affects the spread of the EEG discharge but leaves the trigger mechanism relatively unaffected [568].

Certain visual display units share characteristics in common with television (Wilkins, 1984), and television can induce seizures. Details as to which VDUs and televisions present a risk of seizures, and how this risk can be minimised, have been reviewed for the benefit of patients [615] and those who care for them [610, 565]. Non-pharmacological techniques for treating other forms of reflex epilepsy have also been reviewed [614].

Both sensory and cognitive processes can contribute to epileptogenesis, and are in turn disrupted by it [566, 616].

76.2 Headache (Neary, Wilkins, M Williams)

Mechanisms of migraine [624] and the role of visual stimulation in the induction of headache [628] have been reviewed for the benefit of patients.

The illusions observed in patterns with epileptogenic characteristics provide for a test that may be useful in the diagnosis and management of headache. People with visual or ocular involvement in headaches report more illusions when they observe such patterns, and their illusion susceptibility is elevated both on days when a headache occurs [684] and up to 24 hours before a headache [578]. A collaborative project with Khalil and Legge (Hammersmith Hospital) has investigated contrast sensitivity and illusions in patients with classical migraine whose visual aura occurs consistently in one lateral visual field. Illusions are predominant in that field, and contrast sensitivity is poorer.

76.3 Stroke (Wilkins)

In collaboration with G Plant (National Hospital) the spatio-temporal properties of preserved movement sensitivity have been studied in a patient with occipital lobe damage [581]. Various techniques for rehabilitation following occipital strokes have been described, based on neuropsychological principles [604].

76.4 Other Diseases (Wilkins)

A simple clinical test of contrast sensitivity has been developed [625, 563] and marketed [622], and norms for the test have been published [601]. The test concentrates measurements at one spatial frequency, that at which deficits due to disease are most commonly shown. The test has been shown to have diagnostic value in multiple sclerosis [570], optic neuritis [571], diabetes [569] and glaucoma [585].

An alternative contrast sensitivity test in the form of low-contrast letters has also been published in collaboration with Robson and Pelli of the Cambridge Physiology Department [580] and is currently under evaluation.

76.5 Amblyopia (Watt)

An extensive examination of the condition amblyopia was carried out by Watt in collaboration with Hess, Physiological Laboratory, University of Cambridge [592, 616, 605]. Their finding was that in anisometropic amblyopia, the bad eye behaves exactly as would be expected if the connections between optic nerve and, say, visual cortex were mildly scrambled. No other difference was found. The most likely conclusion is that the optic nerve makes only approximately topologically correct connections with the brain and that these are "unscrambled" during development. The key to doing this lies in the way in which, for a sharply focussed image, near points will have highly correlated patterns of response, whereas far points will be uncorrelated. The pattern of results in strabismic amblyopia is much more complex, and this work has not yet been concluded.

Watt also collaborated with Cowell in a study of a larger sample of patients presenting at the eye clinic of Leicester Royal Infirmary. Using a purpose-designed test chart, the above findings on anisometropic amblyopia have been replicated on 50 patients aged 5-10 years. A longitudinal study, with and without patching of the good eye (the presently preferred treatment) is being considered.

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PSYCHOPHYSIOLOGY

Project 77 - Sleep, Sleep Deprivation and Arousal

77.1 Criteria for Sleep and Wakefulness (Allison, Ogilvie, Wilkinson)

Physiological criteria for sleep and wakefulness were defined, the referent being the behavioural one of the ability to hear and respond (button press) to a tone occurring every 10-20 sec. Sleep/wake transitions were studied repeatedly in this way during the night for correlation with physiological indices of sleep/wakefulness [647, 646, 645].

A review, under contract, was made of the evidence for poor party-wall sound insulation causing disturbance of sleep [660].

77.2 Shift Work (Allison, Wilkinson)

In a study of two systems for implementing night shift work among nurses, on-site performance testing favoured permanent night work for 3 months against alternating weekly day and night shifts [653]. A literature review also concluded that permanent nightshift working is a better solution than to have day and night shifts rotating rapidly (every 2-3 days) or weekly [650].

The EEG event-related potentials P3 and Nd (processing negativity) were both reduced in amplitude by sleep deprivation during an unprepared RT test, suggesting an activational rather than a cognitively-based interpretation of these components.

Refractoriness in choice serial RT, examined by varying response-to-stirnulus-interval (RSI), was reduced by practice and more choices, but unaffected by sleep deprivation: Single channel and preparatory theories were rejected in favour of one of central refractoriness [651].

Portable performance tests (developed 1980-1985) for assessing arousal: Information about these devices, and software for analysing their output, have been provided for many users. A review of the resulting papers in the field of clinical drug evaluation will be published [657].

Project 78 - Human Performance and Its Psychophysiological Concomitants

Decade effects of age on RT were determined by Wilkinson and Allison in a 5325-subject study based on the public exhibition "Medicines for Man" [653].

A study requiring proof reading showed that text checking on a VDU was worse than on conventional hard copy.

78.1 Polygraphs in the Detection of Deception (Levey)

Preparation of an exhaustive report on the reliability and validity of the polygraph in the detection of deception was undertaken by Levey at the request of the Cabinet Office. The conclusion was that the polygraph is not a reliable tool.

78.2 Stress and Coping (Watts)

A series of studies is being undertaken with external collaborators on the relationship between cognitive and physiological aspects of coping with stress. Preliminary work (with Herbert of the Department of Anatomy) examined the relationship between the cognitive and endocrinological aspects of coping with examination stress. We concluded that such research required stresses that are not only predictable, but also prolonged.

A major multi-disciplinary study is now planned, to be coordinated by Herbert, of physiological and psychological aspects of coping with stressful naval assignments. We believe that this will make a significant contribution to stress research; the sample is relatively homogeneous, the stress is predictable, and sufficiently prolonged to produce significant endocrinological change. Also, the range of disciplines and measures involved is also unusually broad in stress research. Watts' contribution will be mainly on perceptual and cognitive measures of coping which have been developed in a study of stress on an overseas school expedition (with Morley of the Department of Paediatrics). The next task is the analysis of data from this study and refinement of the measures.

78.3 Anaesthesia (Levey)

Studies of orienting and arousal in patients under general anaesthesia (Levey in collaboration with Goldmann, Cambridge University) used psychophysiological measures to examine the effects of anxiety on intra-operative anaesthesia [631] and of awareness of events in the operating theatre [633]. It was concluded that patients would benefit from procedures designed to clarify the information made available to them by hospital staff.

Four alternative approaches to the uses of theory in psychophysiological investigations were studied and analysed [636, 635, 637, 638, 639] by inviting short contributions from active workers to a series of journal forums (in collaboration with Martin, Institute of Psychiatry, London). This series continues and should serve to offer a firmer basis on which to integrate psychophysiological methods within the domain of cognitive science.

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COGNITION AND EMOTION

Project 79 - The Interaction of Emotion and Cognition

The development of cognitive approaches to the analysis and treatment of emotional disorders by Beck and others represents one of the major recent achievements of applied psychology. However, this work was necessarily guided more by astute clinical observation and theorising than by the application of experimentally supported accounts of the interaction of cognition and emotion; little in the way of such accounts was available.

One response to the need for experimentally based models of cognition-emotion interaction has been to incorporate emotion into existing cognitive accounts with little modification of the overall framework. So, for example, in associative network theories of mood and memory, emotion is treated in much the same way as other representations. Although this approach has proved heuristic, its difficulties are now widely recognized, and the need for an adequate, experimentally supported framework within which to treat the interaction of cognition and emotion, and from which to derive improved applications, remains.

Johnson-Laird, with Oatley of Glasgow, has proposed a general account of the communicative function of the emotions within a cognitive science framework. Barnard has proposed Interacting Cognitive Subsystems (ICS) as a general-purpose cognitive framework for investigating and solving applied problems. Guided by converging findings from experimental investigations of mood congruent memory and stimulus-independent thought, Teasdale and Barnard have extended this framework to incorporate emotion. ICS provides novel ways for looking at the interactions of cognition and emotion, particularly as they affect the maintenance and modification of affective states, and these form the basis for proposals for future work. Future plans will therefore be described as a whole in one section, rather than following the summary of previous work under each separate sub-project.

79.1 A Communicative Theory of the Emotions (Johnson-Laird, with Oatley of Glasgow)

Johnson-Laird and Oatley have argued that emotions function as communications both within the internal architecture of the brain and amongst members of a social group [685, 679]. They are a more flexible way than "fixed action patterns", and a more rapid way than inferential processes, for preparing an organism to respond. The theory yields several empirical predictions, including the thesis that human emotions depend on the cognitive "modulation" of a small number of emotional modes. A detailed semantic analysis of 590 emotional words corroborated the theory which assumes that there are five basic emotions [716, 685].

79.2 Conceptual Representation of Emotion Terms (Conway, Bekerian)

In a series of studies mentioned earlier, Conway and Bekerian [207] found that emotion terms might be represented in knowledge structures which specify abstract featural knowledge, script knowledge and autobiographical memories of specific emotional experiences. Although different types of knowledge were differentially accessed by different tasks, it was also found that in certain tasks all emotion knowledge types were available for processing. In later studies developing this work, evidence was found to support the view

that autobiographical memories might act as instances of emotion concepts and instantiate the emotion in specific processing episodes.

79.3 Mood Congruent Cognition (Dritschel, Teasdale)

Mood congruent cognition refers to the preferential retrieval or production of material congruent in hedonic tone with the prevailing mood state. Although this is now a well established phenomenon, it is by no means universal. Exploration of the boundary conditions under which mood congruence is obtained provides an opportunity to test and refine theories of its origins.

In a series of studies Teasdale and colleagues have identified the following boundary conditions. For both incidental recall of positive and negative words [686] and for completion of sentence stems [670], biasing effects of mood are greater for self-referred material. Work by Carr, Teasdale and Broadbent found that, within personality trait words, mood congruent retrieval is greater for words related to concepts that subjects use frequently. Mood congruent retrieval for the descriptions used to form images is reduced by inter-item associations between descriptions [689]. This last study also yielded one of the most interesting, and initially counterintuitive, findings. Mood congruence was less for descriptions which had led to images closely related to specific personal autobiographical events (these images were vivid, formed quickly, and did not evoke current feelings) than for images less related to actual specific personal experiences (these images were less vivid, formed more slowly, and evoked feelings as they were created). This finding was replicated both within- and between-subjects in two experiments. Considering this finding within the Interacting Cognitive Subsystems framework led to the proposal that mood congruent retrieval depends on initial encodings that involve high-order generic knowledge complexes related to affective themes. These can subsequently be reactivated by congruent mood states. Image production that requires elaboration from these complexes would, as found, tend to take longer, produce less vivid images, and be associated with production of congruent feeling. By contrast, the lack of mood congruence for descriptions yielding vivid images related to specific autobiographical events occurs because these image descriptions rapidly access records of actual events in perceptual memory, without the need for elaborative processing involving high-order knowledge complexes.

The above proposal provides an account of mood congruent memory that is consistent with the boundary conditions identified by Teasdale and by other workers, and that brings order into the apparent diversity of findings in the field of mood and memory.

79.4 Working Memory and Stimulus-Independent Thought (Baddeley, Dritschel, Proctor, Teasdale)

Beck's cognitive model of depression proposes that the stream of negative thoughts experienced by depressed patients contributes to the maintenance of their depressed state. Consistent with this view, Teasdale and colleagues found [674] that a distraction procedure that reduced the frequency of such thoughts in neurotically depressed patients alleviated their depression. Thoughts unrelated to immediate environmental input (stimulus-independent thoughts, SIT's) were particularly important in maintaining depression. In order to gain a clearer understanding of the cognitive processes supporting the production of SIT's, a series of six experiments within a working memory framework examined interference with the production of SIT's in normal subjects [690, 735]. These studies indicated that tasks interfered to the extent that they required continuous deployment of the control and co-ordinating resources of the central executive of working memory. Consistent

with the view that these resources were necessary for the production of connected sequences of SIT's, in a random number generation task (where randomness has been assumed to depend on these same central resources), randomness was less when subjects were spontaneously producing SIT's than when they were not. Within Barnard's Interacting Cognitive Subsystems framework [249], the central executive control function is instantiated principally by reciprocal interaction between the cognitive subsystem that deals with high-order generic knowledge complexes and the subsystem that deals with propositional knowledge. The finding that tasks interfere with SIT's to the extent that they require continuous deployment of central executive control and co-ordinating functions suggests that reciprocal interaction between these same two cognitive subsystems supports the production of connected sequences of SIT's. This suggestion, and its implications for the maintenance of affective states, are discussed in detail in the proposals for future work.

Practically, these experiments suggest that the effective suppression of unwanted SIT's in insomnia, worry, depression, etc. requires interventions that make continuous demands on central executive control resources. A treatment for insomnia developed by Levey conforms precisely to these requirements, and has been shown to be effective in a preliminary study. Levey and Watts propose to make a more formal evaluation of this treatment.

79.5 Development of a Comprehensive Conceptual Framework for Describing, Investigating and Modifying Cognitive-Affective Interactions (Barnard, Teasdale)

The field of cognitive-affective interaction lacks a conceptual framework that is both sufficiently comprehensive to guide understanding and treatment of patients and sufficiently detailed to guide research on underlying processes. Faced with a parallel situation in human-computer interaction, Barnard has developed Interacting Cognitive Subsystems (ICS) as a conceptual framework that is applicable yet potentially capable of formal modelling. ICS proposes a distributed cognitive architecture, with subsystems specialised for processing information in different codes [249]. The framework has recently been extended by Barnard and Teasdale to include emotion, feeling, and body state, and has been applied to the maintenance and modification of affective state and the effects of mood on cognition [669]. ICS has already provided a useful framework for understanding the results of investigations of mood congruent memory and of the process supporting the production of connected sequences of stimulus¬independent thought. It provides the theoretical rationale guiding proposals for future investigation of cognitive-affective interaction.

Project 80 - Analysis and Treatment of Emotional Disorders

At the time of the last Progress Report, the research on analysis and treatment of emotional disorders was at an early stage of development. At that time it was unclear which experimental paradigms and frameworks would prove to be most useful in the investigation of emotional disorders and what the tractable questions would be. The aim of the work over the last five years has been to lay the groundwork, to define the questions and to assess the extent to which clinical issues can be informed by cognitive models. As part of this exercise, Williams and Watts have collaborated with Mathews and MacLeod of St George's Hospital, London in writing a conceptual and empirical review of research applying cognitive psychology to emotional disorders [663].

The Unit's research has focussed on two ways in which emotion has been claimed to affect cognitive processing: (a) that it impairs general performance on a range of cognitive tasks; (b) that it biases information processing so that the person's perception and memory become dominated by information congruent with their current mood. When this program of research started, much of the evidence for these conclusions was derived either from analogue experiments on student subjects, or, where patients were used, based on subjective reports on their own performance by the patients themselves. The Unit's work in this area, by contrast, has focussed on clinically disturbed patients and people who have fears and anxieties of phobic proportions. It has assumed that successful intervention depends upon careful assessment of the extent to which a deficit or bias actually exists, and examination of what processes underlie it. The results of this application of experimental cognitive methodology to depression, to suicidal behaviour and to phobia are described below.

80.1 Concentration Problems and Memory Deficits in Clinical Depression (Bourke, Cooper, Coyle, Dalgleish, MacLeod, Watts)

80.1a Concentration problems. Previously Watts et al reported descriptive work on concentration problems in clinical depression. These are a source of severe distress to patients and prevent them re-engaging in potentially pleasurable activities. In the present period the relationship between subjective complaints and objective performance deficits has been examined [698].

The earlier work of Watts et al suggested a phenomenal distinction between concentration problems when patients' minds (a) "wandered" or (b) "went blank". They have now found that each is associated with different task performance deficits; mind wandering is associated with poor memory for prose under normal encoding conditions; blanking is associated with poor performance on a planning task, and also with poor recall under more effortful encoding conditions. It is suggested that blanking may be the phenomenal aspect of generalised inhibition of attention that occurs when depressed patients attempt effortful tasks.

80.1b Memory deficits. Research on memory problems in depression has focused on three questions: (i) whether the performance deficit can be explained in terms of response bias; (ii) what cognitive processes underlie the deficit, especially what kinds of material show the most severe deficit; and (iii) what remedial strategies are appropriate.

(i) Depression is associated with poor performance on free recall, but it is frequently suggested that this can be explained in terms of a conservative response strategy. Watts et al's study of recognition memory in depressed patients shows that this is not the case, as there are fewer 'hits' in depressed patients even when 'false alarms' are increased [700]. This provides the first clear evidence that depression affects d' in recognition memory.

(ii) Attempts to identify the processes underlying this deficit have been guided by the hypothesis that depressed patients are deficient in their structuring of material. For example, in a study of memory for prose, depressed patients did not show the normal bias towards recall of units central to the gist of the story. If, in depression, there is a pervasive failure for memory to be biased towards recall of important material, it could have serious consequences for adjustment. In contrast, a non-structural memorial variable such as imageability was found to operate normally in depressed patients [695].

(iii) These results suggest that the memory performance of depressed patients would be helped by the use of images, a memorial variable that is relatively unaffected by depression. Watts et al found that training in use

of imagery produced substantial improvements in memory performance, especially in non-endogenous depression [697]. Another remedial approach would be to improve memorial processes that are affected by depression, and Watts has explored the feasibility of this with students with emotional disorders. This work has emphasised attention to the meaning and structure of material. This project has now been completed.

80.2 Analysis and Treatment of Cognitive Bias in Parasuicide (Dritschel, MacLeod, Proctor, Teasdale, M Williams)

The effectiveness of cognitive therapy in treating depression is well-established [730], and it is currently being extended to other emotional and behavioural disorders [751, 731]. However, there is one group of patients which presents particular difficulties - patients who repeatedly attempt suicide. Despite the scale of the problem (it is the most common reason for emergency admission to hospital in women and the second most common, after heart disease, in men), no psychological treatment has yet been found which reliably reduces the probability of a repeated attempt. The aim of this project is to understand the particular cognitive biases which exacerbate crises to suicidal proportions and, in future work, to study how such biases interact to bring about chronic hopelessness and schizotypal cognitive disorganisation.

The starting point for the research was the finding by Teasdale and colleagues of biased autobiographical memory in depressed mood. In Williams' early work, he found that suicidal patients had a similar memory bias, but also showed a more general deficit which had not previously been described: they had difficulty in focussing on specific events, responding instead with general memories (e.g. "going to parties"; "arguments with my boyfriend") [709]. Patients had particular difficulty in giving specific memories for positive events. Subsequent studies found that this difficulty in responding with specific memories was a reliable phenomenon, and occurred in patients who were able to perform normally on other cognitive tasks [707, 738].

There are a number of possible causes of this phenomenon. First, parasuicide patients may have a different cognitive style from other people. Second, their transient disturbed mood could be disrupting memory. Third, since these patients had undergone recent stressful events, these could be affecting memory quite apart from mood. In order to answer these questions, Williams and colleagues studied patients who were currently depressed but not suicidal [683, 714], and ex-patients who had taken an overdose some time previously but who had not had a recent life event [710]. These studies found (a) that depressed people who have no history of suicidal behaviour show a similar pattern of overgeneral memory to that shown by overdose patients, suggesting that the phenomenon is not peculiar to suicidal people; (b) that the extent of overgeneral recall does not correlate with the extent of mood disturbance, suggesting that transient mood is not itself a sufficient explanation of the phenomenon; (c) that ex-patients who have recovered from their suicidal crisis still show an overall difficulty in specific retrieval, suggesting a cognitive style of overgeneral encoding or retrieval which outlasts individual crises; (d) that these ex-patients were nevertheless relatively more specific in retrieving positive events than negative events suggesting that the presence or absence of a recent life event does play a role in the extent to which retrieval processes are disrupted.

80.3 Cognitive Vulnerability to Depression (Teasdale, Williams)

Based on his earlier investigations of the effects of mood on cognitive processing, Teasdale has developed a cognitive account of vulnerability to depression [687]. This proposes that individual differences in the nature of

the cognitive constructs that become accessible in mildly depressed states represent an important factor determining whether such states remain mild and transient or become more severe and persistent. Studies using a self-referent incidental recall paradigm with community samples have supported predictions from this account both with respect to onset [688] and persistence [671] of depression, and an independent study in Oxford has produced further supportive evidence.

In parallel with this work, Williams has extended the cognitive vulnerability model to account for the way in which cognitive distortions interact with biological processes (especially circadian rhythms, [675]) in determining the course of depression and response to treatment in endogenous depressives. In a study in collaboration with Healy and Paykel of the University Department of Psychiatry, Williams and Teasdale examined the extent to which cognitive distortions predicted persistence of depression in endogenous depressives undergoing treatment. The self-referent incidental recall task failed to predict outcome, but a measure of dysfunctional attitudes taken when the patients were first admitted predicted outcome independent of initial severity, consistent with the cognitive vulnerability theory.

80.4 Cognitive Therapy of Depression and Anxiety (Teasdale, Williams)

Cognitive therapy, pioneered by A.T. Beck, aims to treat clinical states such as depression and anxiety by altering the maladaptive patterns of cognition that support them. Although no longer involved in direct clinical investigation of these treatments, Teasdale and Williams continue to be invited to review developments in outcome and process research [719, 721, 720, 728, 750, 729, 751, 753] and to provide consultation to other researchers in this field.

80.5 Processing of Emotional Stimuli in Spider Phobia (Bourke, Cooper, Coyle, Dalgleish, MacLeod, Watts)

During this period Watts et al have published work described in the previous progress report indicating that phobic stimuli recruit attentional resources. This is exemplified by retardation on the 'emotional Stroop' paradigm in which subjects are required to name the colour in which spider-related words are printed [699]. Colleagues have used the same paradigm in studying suicide attempters and worriers, and it has subsequently been used very extensively by researchers in other centres.

During the current period, Watts' research has focussed increasingly on the hypothesized poor processing of the stimulus features of phobic stimuli. The central claim is that anxiety interferes with the encoding of phobic stimulus features. This is held to have the following consequences: (a) memory for phobic stimuli will be poor, (b) cognitive representations of phobic stimuli will be relatively undifferentiated, and (c) emotional habituation to phobic stimuli will be limited, and the therapeutic benefit of exposure treatments thereby diminished.

(a) Phobics have poor recognition memory for spiders, a phenomenon that is due to reduced discriminability rather than response bias [705]. A similar phenomenon has been found with memory for phobic words; phobics show poor memory for spider stimulus words (compared to control subjects and control words). The effect is strongest in phobics in whom phobic anxiety is currently activated. Poor memory appears to be specific to stimulus words relating to spiders (e.g., hairy); in contrast memory for words relating to the anxiety response to spiders (e.g., frightened) is enhanced. The general conclusion is that phobic anxiety impedes the

encoding of phobic stimulus features, a key point on which Watts' theoretical position differs from the related theory of Peter Lang [694].

(b) Watts et al had previously provided evidence that phobic representations are relatively undifferentiated by snowing that phobic constructs are more highly correlated in phobics than controls. In extending this work, with improved controls, it has been found that there are particularly strong correlations in phobics between typicality ratings and ratings of detailed stimulus features of the phobic object [737].

(c) In a study of desensitization Watts et al found that phobic representations are relatively unaffected, at least in the short-term, by desensitization treatment, whereas phobic attentional phenomena showed a rapid response [705]. Further work on desensitization is planned.

Work has also been undertaken to explore the implications of this line of work for clinical groups. Following the argument that good functional exposure is particularly important in the exposure treatment of agoraphobics, studies of attentional strategies in agoraphobics have been undertaken [693]. Preliminary work has also been undertaken on processing impairments in compulsive checkers, and their treatment implications.

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