Progress Report
1954-1960

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Miss J.A. Kelly, BSc

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Former Staff (during period covered by report)

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Honorary Advisers

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Professor G.C. Drew, MA (until 1958)

Attached and Visiting Workers

P. Bakan, PhD (Michigan State University) (1956-1957)

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D. J. Bradley, BSc (CSIR, Johannesburg) (1956-1957)

P. Bertelson, Lic.Sc (University of Brussels) (1957)

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S. Kornblum, PhD (University of Michigan) (September 1960)

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The Unit is concerned with measurable aspects of human intellectual and manual performances under normal conditions, and also under a range of unusual environmental conditions. Research problems are selected upon two criteria. First, to provide general, "basic" or "theoretical" information about human behaviour. Many of the results have been reviewed from this point of view in Perception and Communication (Broadbent, 1958d). The second criterion of selection is to supply practical answers on issues of current importance. Many such answers have been included, together with information from other Units and outside sources, in Human Factors in Design and Use of Naval Equipment (R.N.P.60/962), a report produced for the Royal Naval Personnel Research Committee by a working party of which Poulton was a member. The researches mentioned in the following pages thus form only a highly selected part of the Unit's activities over the period in question.

The dual approach through theory and practice is sufficiently distinctive to attract large numbers of visiting academic workers and of requests for practical advice. Many applications of both types have to be refused. The summary of research which follows is built on the following plan, A man doing a job can be regarded from four aspects. First, there are the background conditions of work: heat, noise, etc. Second, there are the stimuli striking his senses: to which and to how many of these does he respond? Third, there are the internal operations performed on this information: the storage of items in memory, or the choice of particular actions. Fourth, there is the execution of actions once they have been chosen. Some research has been done in each of these areas, and although the division is somewhat arbitrary it has been used for want of a better.

THE BACKGROUND CONDITIONS OF WORK

Hot and humid climates

Pepler's experiments carried out at the Council's Royal Naval Tropical Research Unit in Singapore have now "been fully analysed. The Navy has been advised that for men used to living in the tropics, the effective temperature of a compartment should not be allowed to rise above 81°F., or working efficiency will be likely to fall off (Pepler, 1958). This corresponds to the upper limit of 79°F. for men living in temperate climates, suggested previously by Mackworth. In the sedentary occupations which are now typical of the modern Navy, and also of modern industry, the measures of intellectual performance used by Mackworth and Pepler are more sensitive to changes in heat and humidity than are physiological measures such as heart rate and body temperature, which are still the most commonly used. In many cases there is no correlation between such measures and psychological ones. Mackworth and Pepler were among the pioneers in the use of performance measures in this field. The implications of their work have not yet been sufficiently widely recognized.

The scale of effective temperature combines into a single index the readings of wet - and dry - bulb

thermometers and the rate of air movement. Because of its relative simplicity, it has been used in research to specify hot and humid climates. However, the scale is based upon subjective feelings of warmth, not upon measures of performance. Pepler (1958 Fig.3) made the discovery that at the same effective temperature damp heat is more detrimental to working efficiency than is dry heat. A revised scale is thus called for, which is related directly to working efficiency.

Loud noise

Broadbent has directed one of the very few fully-controlled experiments ever to be undertaken in industry into the effects upon production of reducing an excessive level of noise. Reduction of the level of noise in acoustically-treated bays from about 100 decibels to about 90 decibels above .0002 dynes/sq.cm. significantly reduced the amount of spoilt work and breakdowns attributed to the operators, as compared with untreated bays. Rate of work was unaffected by the change in noise level (Broadbent and Little, 1960). This result was predicted by Broadbent's theory (l957g) that noise increases the number of momentary lapses of attention. In laboratory studies Miss Woodhead has shown that a short loud burst of noise from a rocket firing can upset decision-making for up to 30 seconds, provided ear protection is not worn (Woodhead, 1959; 1960b). Knowing when the noise is coming is of little help (Woodhead, 1958). The present position concerning the effects of noise upon behaviour is given in Broadbent's Chapter 10 of the Handbook of Noise Control (an American publication) (Broadbent, 1957c).

Loss of sleep and level of arousal

Wilkinson (1959a, 1960a) has been able to prove effects on efficiency from only one night's loss of sleep. The tests used need to be prolonged and unstimulating; if the task is made complex or "arousing", not only is it performed better but the effect of loss of sleep disappears (Wilkinson, 1960b). (There is some evidence that this is one of the differences "between sleeplessness and heat.) Even in men who have slept normally, Bakan (1959) showed that fewer signals were missed in a watch-keeping task if an extra job was added which kept the man attentive. Equally Colquhoun (1959c) demonstrated the benefits of a short rest pause on a task resembling industrial inspection. But increasing the level of stimulation is not automatically a good thing. Poulton (1960c) found that prolonged performance was maintained better on a task of moderate complexity than on similar tasks which were either more complex or simpler. The circumstances under which rises and falls in stimulation may cause a drop in efficiency are somewhat complicated, and are now engaging a good deal of research effort.

Other future plans

These stresses are being combined in pairs and triplets to see whether the combined effects can be predicted or not from a knowledge of the separate effects. The ways in which different individuals react to environ¬mental stresses are also being examined. It is already clear that the detrimental effects of each stress

on behaviour are different from those of other stresses, and that certain tests of personality are related in a complex way to performance in stimulating as opposed to unstimulating conditions.

THE INTAKE OF INFORMATION INTO THE MAN

Selection of some stimuli from an array

It is often assumed that the controller of complex machines (aircraft, power stations, etc.) should be given all the information technically possible about the processes he is controlling; even if this means an immense array of dials and indicators. N.H. Mackworth and J.F. Mackworth (1958a) have shown however that decisions can be retarded by giving a man too much information. Facts which are not strictly necessary should either be withheld, or else made easily distinguishable from relevant information (N.H. Mackworth and J.F. Mackworth, 1959). This principle has since been followed with great benefit in important practical control systems.
A distinction must however be made between the problem of too many factors requiring simultaneous consideration (load stress) and too little time between successive decisions (speed stress). Experiments by Conrad (l954a) have examined both factors in detail. Amongst other points, he showed that the time taken to deal with an item of work depends on the rate at which items are presented to a man. This principle was further demonstrated when an operational Post Office telephone exchange was run under controlled experimental conditions for five weeks (Conrad and Hille, 1958a). The results of the experiment led to substantial staff reductions. (This speeding-up of men faced with an increase in the rate of arrival of stimuli may not be unconnected with the beneficial "arousing" effects of stimulation already mentioned.)

When information may be sought from a number of different possible places, different strategies of search become very important. Thus in looking for faults in radios and other electronic devices, a systematic step-by-step procedure is most efficient on average. But Dale (1958c) has shown that even experienced repair men do sometimes abandon this procedure and take the risky step of guessing that examination of a particular point will find the fault. Such a spot diagnosis is of course highly spectacular if successful, and the known low probability of being correct by chance may give the impression of remarkable clinical acumen. But equally the guess may be wildly incorrect, and on the average this is an inefficient strategy. There are therefore implications for training (Dale, 1959b), which have been taken up by R.E.M.E. and the R.A.F. The topic also links up with the whole problem of the choices made by men in situations where risky alternative actions are presented for decision, a question of much interest to academic psychologists at the moment.

Simultaneous response to two channels of stimulation

In an investigation of a specific problem, Broadbent (l958d Chap.4) used a method which has since been brought into more general use. The problem was that of the value of frequency-selective circuits when applied to transposed speech such as may result from the mistuning of a single-side-band radio receiver. Amongst

other findings, it was noted that transposed speech was equally intelligible with and without removal of the low frequencies (bass cutting). But if the listener had to perform a visual task (tracking a wavy line with a pointer) while listening to speech, this secondary task was performed better when bass cutting was in use. This suggested that bass cutting did help the man, in that it left more of his spare mental capacity available for the tracking.

Poulton (1958b) employed this technique of the additional task to evaluate the relative merits of two designs for a piece of equipment, both of which appeared adequate when operated alone. He used a subsidiary listening task, which the man had to perform when he could, as a measure of spare mental capacity. The better design of equipment gave fewer errors on the listening task.

It follows from this work that rival designs of equipment should be evaluated under conditions which are at least as exacting as any that will be met in actual operations with the equipment. If this is not done, a design may be chosen which at peak periods demands more of the man's mental capacity than he can safely spare from his other activities. This approach to the evaluation of equipment contrasts strikingly with the usual assumption that an instrument which is satisfactory in isolation will still be so when combined with a number of others.

It should also be noted that performance of one task may be impaired not merely by response to another channel of stimulation, but even by the need to be ready to respond to another such channel. This has been shown by Broadbent (1956a) in an artificial situation, and by Brown, Holmqvist and Woodhouse in one resembling an aircraft cockpit more closely. In the latter case a visual task intended to represent looking out for landmarks was interfered with by a second task of flying the simulated aircraft. In another condition the latter task was supposed to be under the control of an autopilot, and the "pilot" had merely to be ready to take over from the autopilot instantaneously if it failed. There was just as much interference with the "looking for landmarks" in this latter case. Thus the mental load on the pilot cannot he measured fully by the methods of Work Study (observation of actions); it includes what he has to hold himself in readiness to do at very short notice, as well as what he is actually doing. This is a point which has not been sufficiently considered in such problems as deciding the size of crew required in future high-performance commercial aircraft.

Specific types of stimulation

(a) *Visual*. It is often necessary to determine the best way of delivering a particular type of information, by comparing various modified forms of stimulation. Thus Poulton (1959a) has compared various different printing types and formats, by presenting to various scientists identical information printed in different ways. Comprehension was better when the style of Proc. Roy. Soc. A and B was used, than when the material was in other styles commonly employed for scientific journals. To take more technological examples, Baker (1958) has devised a modification of the Plan Position Indicator radar display, so as to draw attention to the important outer ring. It is in that part of the display that incoming raiders will often first appear, but equally that is the

part where they are less likely to be seen on the traditional P.P.I, Bowen and Woodhead (1955) have also examined the type of displays which give the most accurate predictions of the future course of an aircraft.

(b) *Auditory*. The development of machines which will synthesise speech sounds has opened a new field for the study of hearing. In joint research with Ladefoged of the Phonetics Department, University of Edinburgh (Broadbent and Ladefoged 1957a) it has been found that sounds in different parts of the spectrum must be amplitude modulated at the same frequency if they are to be heard as speech from a single voice. This result has very considerable implications for our understanding of the way the ear works.

In another series of experiments (Broadbent and Ladefoged, 1957b) it was found that the interpretation of a synthetic vowel sound depended upon the nature of the vowels in the synthetic sentence which preceded it. Thus a sound which could be taken to be either of two words when heard alone, was interpreted according to what the listener knew of the characteristics of the "speaker's" voice. These findings, and results on the perception of the order in which auditory signals are presented, establish at least some of the principles of auditory perception to set beside the known principles of visual perception. In addition they are of some value for the design of better telephone systems, using less band-width.

Future plans

It is likely that mathematical theories of decision in risky situations will become more important in analysis of how men pick certain stimuli out of their environment. Work on these lines is in progress.

CENTRAL PROCESSES IN THE HANDLING OF INFORMATION

Choice reactions

Once a man has perceived a stimulus, he has to select the appropriate reaction to it. When he is dealing with a series of successive stimuli, as in the cycles of an industrial operation, he does not take exactly the same time for every decision even when he is fresh. As he tires, his rate of work tends to become still more variable, although his average rate may not decline much. If the time allowed for each cycle of operation is fixed rigidly by machine, time will be wasted when he happens to perform a cycle particularly fast, and he will fail to complete a cycle when he happens to be working particularly slowly. These sources of inefficiency are eliminated if the man can work at his own speed. Thus from the times taken to sort successive letters on a letter-sorting machine when the men had been able to set their own pace for a year, Conrad (1960a) calculated that they sorted at a considerably faster rate than they could have done if the pace had been set by the machine. This contradicts the assumption of many industrialists that a machine can always make a man work faster than he will do otherwise: this belief probably arises from a partial understanding of the facts of arousal mentioned earlier.

Leonard (1953) showed that a man worked faster and with less effort in a sequential laboratory task when he was allowed to see the display item to which he had to respond next while he was responding to the present item. Seeing more than one item ahead offered no further advantage. The Mackworths (Mackworth and

Mackworth, 1959; J.F. Mackworth, 1959) following an earlier experiment by Poulton, found that when the eye-voice or eye-hand span was increased artificially beyond one item, performance became less accurate unless the man was allowed extra time in which to rehearse the items in his memory store.

When a man could see only one display item at a time, Leonard (1958b) found that a machine which inserted a compulsory delay between the appearance of the item and the time at which his response to it became effective, slowed him up rather more than the duration of the compulsory delay. All this work is relevant to the problems of the Post Office in sorting letters by machine, as well as to many other situations.

Short-term memory

Broadbent (l958d, p.212) presented a string of three digits to one ear and a different string of three, digits simultaneously to the other ear. He found that the experimental subject normally reproduced one string before the other. When he had to reproduce first the two digits arriving first at each ear, second the two digits arriving second and so on, errors were over twice as frequent. Results were substantially the same when the two strings of digits were presented one to the eyes and one to the ears, or both to both ears but one in a high-pitched voice and one in a low-pitched voice (Broadbent, 1956b). These findings, and the results described in the last Progress Report on listening to more than one voice at the same time, have led Broadbent (1957b) to develop a mechanical model for human attention and immediate memory, Conrad (1960c) found that 8-digit numbers were reproduced more accurately after very short delays than after longer delays. Simply having to insert the prefix 0 before reproducing the 8 digits doubled the chances of an error. This work throws new light upon the nature of immediate memory, and has led to recommendations to the Post Office on the use of long telephone numbers in automatic trunk dialling.

Poulton (1958c) presented different numbers of short statements during a fixed time interval of three minutes. He found that within limits the number of statements which could be recalled soon afterwards was independent of the number presented. Unfamiliar ideas were much less likely to be remembered than familiar ideas. These results draw attention to some possible dangers in skimming and fast reading.

This area is one in which the evidence is exceedingly complex: but tentatively one may say that all these results, taken together with work from other laboratories, suggest the presence of a mechanism for short-term memory quite different from that used for long-term memory. Such a distinction has of course long been familiar in theories of the brain put forward by cyberneticists, since Computing machines often have two types of memory.

Future plans

It has recently become clear (see Leonard, 1959) that familiar stimulus-response combinations act in an unusual fashion when choice reactions are being made. This again raises the question of the applicability to human behaviour of mathematical theories of decision, and further investigations of the topic are already in progress.

THE EXECUTION OF ACTIONS

In tracking, Poulton found that a pursuit display, in which the man matches the movement of an object with another object, gives greater accuracy than a compensatory display, in which a moving object has to be held as nearly stationary as possible over a fixed reference marker. This is because a pursuit display enables the man to see the movement which he is attempting to match, and thus to predict its future course. He performs most accurately when he can see the display all the time, even though he only alters his control movements intermittently (Poulton, 1957a). These principles are used in a new device for displaying flight-director information to the pilot of an aircraft. The work has led to a clearer understanding of the role of prediction in the skilled movements of everyday life (Poulton, 1957c): it is clear that a strong perceptual element enters into these apparently motor tasks.

A long-needed labour has been started by Gibbs, who has compared the speed with which the thumb, the hand, and the forearm can move a control so as to bring an object into line with a target. This comparison must of course be made at various sensitivities of control, with various lags between the control movement and its effect, and so on. So far the hand appears slightly superior, and the best sensitivity of control has been found for the particular conditions (initial distance of object from target, etc.) of the experiment. Further data are now being collected with these conditions modified. It is hoped that the results will be of value to all engineers concerned with the design of power controls.

Future plans

The ultimate interest of this area of research is that it suggests parallels between closed-loop servo-mechanism and the actions of men. It is possible that when people acquire a skill, they do not learn solely to carry out a certain series of muscular contractions, but rather to act as closed-loop servos seeking certain goals. If this is so, further work upon the lines started by Gibbs should help to reveal it: particularly if one examines the effects of experience with one control upon performance with another.

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