HUMAN PROBLEMS OF WORK DESIGN

SAMUEL JOHNSON once observed how quietly people will endure an evil which they might at any time very easily remedy; he gave as an instance a family which had possessed an island for more than four hundred years and never made a commodious landing-place, though a few men with pick-axes might have cut a staircase out of the rock in a week's time. At the recent meeting of the British Association at Newcastle upon Tyne, Section J (Psychology) held a discussion on the "Human Problems in the Design of Machinery and Working Methods", and it was emphasized that, although knowledge is increasing, even modern communities have as yet little scientific understanding of these questions. In fact, Dr. Johnson's remark still holds good to-day, because many instances were quoted at Newcastle in which ordinary common sense has been lacking in the planning of the physical, psychological and social environments in which men work.

Dr. N. H. Mackworth (Applied Psychology Research Unit of the Medical Research Council, Cambridge) said that the first step is usually to identify really troublesome factors in the working situation, and that often this cannot be done by just a verbal description. A reliable diagnosis of the causes of reduced ability often depends on a careful, systematic and graded series of quantitative tests in the laboratory to study measurable changes in human performance, when the effects of many possible causes have to be disentangled. The physical dimensions of the human environment are varied in these tests to see how the human ability of healthy men fares in the new situation. Instances of this approach were chosen by Dr. Mackworth from very simple forms of work. An investigation was quoted in which the distance between the subject and his reading material was increased, and the maximum distance determined at which the material became difficult to read. Since there was clearly also a minimum distance at less than which the material again became difficult to read, there was obviously an optimum range for the reading distance within which alterations in this one physical factor made no difference at all to reading performance.

Just as in a visual experiment one can be too far from or too near the object of regard, clearly one can be too cold or too hot for effective work. In other words, this indifference range for the reading distance can readily be compared to the range of variation possible in the thermal environment without any measurable influence on human ability, although such changes are, of course, easily perceptible. Field tests far below the lower limits of this thermal indifference range were described in which the extremely cold, dry atmospheres of -25°C . to -35°C . gave considerable, but temporary, tactile changes in the fingers during three minutes of exposure. These sensory changes are particularly affected by differences in wind velocity, and an increase in wind speed from 0-2 m.p.h. to 6-10 m.p.h. gives a four-fold increase in the amount of this numbness at such low temperatures. There are also signs that local cold-acclimatization can occur in the hands, since less numbness is measured in men whose ordinary duties entail daily exposures to very low temperatures. This acclimatization effect is found with moderately severe wind conditions, and can be

demonstrated only in this highly specific environment. Brief mention was made of the effects of high atmospheric temperatures on human ability, with particular emphasis on the laboratory findings that graphs of errors in performance either in mental or muscular tasks give logarithmically shaped curves when plotted against room temperature. The critical room temperature above which physical and mental human ability is usually reduced in laboratory tests is about 93°F . dry bulb and 83°F . wet bulb; temperatures about this level are not unknown in coal mines in Great Britain.

Dr. Mackworth then went on to describe the influence of a further physical factor—the effects of the time allowed to do the work. Some mention was made of researches on the results of allowing too much time to complete a task, especially as regards the loss of accuracy following boredom effects in visual look-out duties, but most emphasis was laid on situations where time is too short. Reference was made to the influence of speed stress (as demonstrated in the unpublished work of Vince and Conrad respectively) in terms of its effects on accuracy of simple manual movements, and on accuracy of reporting visual signals from a multiple-dial display. Comparisons were made between these results and the findings with a high-speed mental task in which the time allowed per decision is gradually reduced. Speed stress in mental tasks has been shown also to depend partly on the mental load, that is, the number of separate streams of incoming signals requiring simultaneous consideration. When increased, this mental load factor can raise the average error score, even if the number of decisions per minute is kept constant. Evidence of this kind suggests that work design need not be limited to manipulative tasks; a further detailed mathematical analysis of human behaviour is feasible, and this might even assist in the planning of more intellectual forms of work. This approach would open the way for much-needed studies of more complex aspects of human behaviour.

Another likely trend for future laboratory researches is the extension of the idea of work design to conserve human effort in ill-health; for example, in patients with limited energy as a result of chronic heart disease. Common-sense rules have already been outlined for this condition by the New York Heart Association, and further quantitative experimental work is now urgently required on this and similar problems of the design of the environment to suit some given bodily disability. Since good work design can also at times prevent accidental injuries and deaths, the practical aspects of this actively growing research subject are three-fold: an easier working task for the healthy man, a more agreeable and longer life for the sick man, and the prevention of minor and fatal accidents. A great deal of information of more general interest can also be simultaneously gathered from such studies to contribute towards the limited store of exact theoretical knowledge so far available on human behaviour.

The next speaker, Dr. C. B. Frisby (National Institute of Industrial Psychology, London), outlined three ways in which occupations may affect people: the physical requirements, the psychological constraints and the social demands. The physical demands of work have been studied for years by applied psychologists, industrial physiologists and production engineers. Movement study methods have given rather *ad hoc* information which is not sufficiently concerned with the principles of the

subject; nevertheless, much highly specific information has been obtained on this aspect. Psychological aspects of work design deal with work simplification problems by reducing the physical effort entailed, and by avoiding so far as possible the need to make decisions and exercise judgment. Due attention has, in fact, been paid to the need to reduce cognitive effort, for example, by supplying working materials in the fixed and predetermined order in which they would be required. Not enough research effort has, however, gone into studies of the psychological aspects of work design as regards the emotional aspects of occupations, as, for example, the motivation and satisfactions derived from the working situation. The social influences in occupations include factors such as (1) the effects of grouping people together at their work in different ways; (2) the result of particular methods of payment by results, in which the work of one man can at times largely determine the payment received by the whole of his group; and (3) the restrictions on social activity imposed by barriers to hearing and seeing.

Dr. Frisby held that an analysis of the workers' motivation and satisfactions with their work is of fundamental importance. So far, the attention of sociologists has been directed mostly towards questions of policy and management, and, important though these are, it is unwise to neglect the study of the job itself. Very seldom is the worker consulted about the working methods he has to employ. This emphasizes the element of compulsion and handicaps the sense of participation in the enterprise. The opportunities for creative expression are also reduced by a greater and greater subdivision of work, which means that the visible change in the material made by any one operator becomes smaller and smaller. Social compensations in the work-place make up for this, particularly with women workers, and propaganda on the social value of the finished product can also indirectly counteract this drawback. Short of actual creative expression there are often, however, strong satisfactions to be gained even with fairly simple tasks from a pride in skill. Much work remains to be done, however, on the size of the unit work cycle and the complexity of the task to determine the critical point on subdividing the work at which even this pride in skill disappears in those who are normally so employed. It is thought that this critical point may depend to some extent on the level of intelligence and special aptitude of the individual worker.

A sense of achievement can be fostered by remembering that the quantity of work issued as a batch to the workman often acts as a milestone. This target should, therefore, not be too distant, since it is known that the rate of work is often higher with smaller batches. The National Institute of Industrial Psychology is working for the Human Factors Panel of the Committee on Industrial Productivity under the chairmanship of Sir George Schuster on these two related questions of the best size for the unit work cycle and the best size for the batch supplied.

Sociological effects also arise from special production systems with subdivision of the work, because it usually means that the work is done by a group of workers rather than by one person. Differences between the working speeds of different workers often have the effect that the speed of the group is set by the slowest member. When the conveyor belt is moving quickly because the work has been broken up into short tasks, such difficulties are very likely to arise; and for this the provision of small buffer

stocks of raw material between operations or groups of operations is often helpful. The possibility of more variety in work also needs consideration. For example, workers in a team might change jobs at certain stages in the day, or a worker might regularly conduct two or more processes alternately, changing at regular time intervals or on finishing a batch of work. Such systems are often more acceptable when introduced at an early stage of training so that the method is taken as a matter of course.

Dr. Frisby maintained that many sources of satisfaction exist in the work itself, which are as yet unexplored and unclassified by research investigators. It was possible that kinæsthetic sensations provide one example of this type of satisfaction, and L. G. Fuchs, the blind investigator, has made some preliminary studies along these lines. Many more researches are, however, required to study these important questions related to the satisfactions to be found in the work situation itself.

The last paper was by Wing-Commander H. P. Ruffell Smith (Royal Air Force Institute of Aviation Medicine), who emphasized that man's use of hand tools has evolved their traditional sizes and shapes over thousands of years. But the advent of the machine tool and of powered transport has quickly stressed the urgent and immediate need to fashion these new types of implements to fit the abilities of man much more exactly. One reason for this evidence of the neglect of work design is that the users of such elaborate tools cannot easily take part in their design or construction. Secondly, great technical advances in machinery have at first hidden the fact that correctly designed equipment may add even more to the speed and quality of work obtainable with these new devices. A third reason for the lag in the application of principles of work design is that people sometimes tend to choose tools by appearance rather than by function.

During the War, many flying accidents were due to faulty design of aircraft. This was because, in flying, any error due to the misuse of a control or the misreading of an instrument could easily lead to abrupt disaster. The Royal Air Force set up a research organisation which dealt with the subject of work design under three headings: the atmospheric surroundings, the personal protection of the airman, and the work-space in the aircraft. Wing-Commander Ruffell Smith dealt in detail with questions arising in the design of the aircraft working space—matters such as the dimensions, view out, controls, information, crash protection and escape. The year 1946 saw the first serious attempt of the Royal Air Force to plan work space in aircraft. Three facts stimulated this development—war-time experience of injuries due to the crash hazards of aircraft structure, accidents due to the misuse of controls, and the advent of the ejection seat. Dr. G. M. Morant has obtained anthropometric data from a thousand pilots, particularly the maximum readings for shoulder width, sitting height, thigh- and leg-lengths, and the minimum readings for the total arm- and leg-lengths. These data suggest an ejection of path 28 in. long and 27 in. wide.

The piecemeal adjustment of one item after another in the cockpit has been found unsatisfactory, and the Cockpit Layout Committee was formed to bring together the experience of pilots, medical men, men of science and aircraft designers. A skeleton model of a single-seater cockpit was constructed in which it was possible to vary any dimension at will. Pre-

liminary discussions pointed to the importance of the following factors: the view over the aircraft nose, the distance of the eye to the instrument-panel, the distance of the eye to the gun-sight, the crash distance of structures forward of the head, adequate clearance for the ejection seat, the controls to be easily within reach, the seat height and rudder-bar positions to be adjustable. From these early data a more elaborate mock-up model was then constructed, and the position and mode of operation of some two hundred instruments and controls determined. Certain principles are now common practice and are employed in all new aircraft built for the Royal Air Force, the Royal Navy and for civilian air lines. Standardization has also been agreed with the United States Services except for a few items. These important principles are (1) separation of controls into pre-flight and flight; (2) the separation of flight controls into throttle and control-column sides; (3) the distinction of controls by position, method of operation and knob-shape; (4) emergency and stand-by controls to be an over-action of the normal control or placed near the normal control; (5) controls to act in the expected direction, and the position of control surfaces to be indicated in the same way; (6) all controls to be set up forward for take-off; (7) standardization of the arrangement of flight instruments, and all engine-monitoring instruments to be arranged for rapid appreciation.

Much other work has been done on this problem of making man and aircraft a harmonious team; the tasks of other crew members are now being studied—those of the navigator, the flight engineer and the radar operator. New problems are, however, constantly being set by the swift evolution of aircraft and other equipment. These rapidly changing requirements stress once again the need for investigations directed towards discovering the principles of the subject, rather than for studies which are only *ad hoc* investigations.

N. H. MACKWORTH

BIOCHEMISTRY AND PHYSIOLOGY OF THE CELL

AT the meeting in Newcastle upon Tyne of Section I (Physiology) of the British Association on September 6 the presidential address on "The Cell" by Prof. R. A. Peters was followed by a group of papers on particular aspects of cellular physiology. Prof. Peters emphasized that recent work upon organised enzyme systems has already produced therapeutic results. In illustration, he chose two poisonous substances, iodoacetic acid ($\text{I}\cdot\text{CH}_2\cdot\text{COOH}$) and fluoroacetic acid ($\text{F}\cdot\text{CH}_2\cdot\text{COOH}$), which have similar chemical structures but very different types of biochemical action. The iodine atom of the iodoacetic acid can easily take part in substitution reactions at neutral pH values, whereas the C—F group in fluoroacetic acid is very stable.

Iodoacetate owes its toxic properties to its ability to combine with —SH groups in certain enzymes, such as the triosephosphate dehydrogenase of muscle which is particularly sensitive, so that when muscle tissue is poisoned with this substance, lactic acid formation is completely stopped. The oxidation of pyruvate by the pyruvate oxidase system also depends upon —SH groups, but in this case a specific poison is to be found in the arsenical lewisite ($\text{CH}_3\text{Cl}:\text{CH}\cdot\text{AsCl}_2$), which attacks a specially arranged

dithiol grouping. Its action can be reversed by British anti-lewisite (BAL) (dimercaptopropanol), which is now used clinically as an antidote in cases of arsenical dermatitis and other similar conditions. Since the pyruvate oxidase requires thiamin pyrophosphate as a co-enzyme, vitamin B₁ deficiency induces a biochemical lesion affecting the same enzyme system.

Fluoroacetate, which is the toxic principle of the South African plant known as 'gifblaar' (*Dichapetalum cymosum*), is very poisonous indeed, especially to mammals. Its toxic action is exerted on the central nervous system and on the heart, but is not due to the liberation of fluorine. Fluoroacetate has no action on any known isolated enzyme system, but it decreases the oxygen uptake of slices of kidney tissue and causes an accumulation of citrate. Such an accumulation of citrate is also found in the tissues, especially the heart and kidneys, of animals poisoned with fluoroacetate. Citric acid and related 6-carbon tribasic acids are formed in the operation of what is known as the citric acid cycle, being produced by the condensation of oxaloacetate with an active 2-carbon compound formed from pyruvate or even from acetate. The acids of the citric series, including *cis*-aconitate, then give rise to α -ketoglutarate, which in turn forms succinate and finally oxaloacetate, which starts the whole cycle again. Prof. Peters suggested that fluoroacetate does not compete with acetic acid for entry into the citric acid cycle, but that it is activated by the same enzyme as acetate and, in fact, enters the cycle. Since the foreign molecules so formed cannot be handled by one of the enzymes at the tricarboxylic acid stage, the foreign molecule jams the cycle and so leads to a gradual accumulation of citrate. Fluoroacetate is therefore poisonous, because it is so like a normal metabolite that the tissue enzyme concerned cannot distinguish between it and ordinary acetate.

The toxic actions of both iodoacetate and fluoroacetate can therefore now be explained on the basis of modern enzyme biochemistry.

Prof. Peters next turned to the question of the biochemical organisation of the cell and the location of the organised complexes of enzymes. Many such complexes are to be found in the granules in the cell cytoplasm where they may be arranged, not in a haphazard manner as if the granule were a mere bag of enzymes, but in a regular orientation of structurally related enzymes, spatially distributed in relation to each other in an appropriate pattern which can be upset by biochemical methods. In this arrangement, surface factors play a fundamental part even down to a molecular level, and the surfaces of separation in the cell may have an individual organised structure.

Any hypothesis of cell organisation has to explain the ability of the cell to conduct, at the same time, various chemical reactions which individually require quite different physico-chemical environments, that is, the cell has to act as a 'micro-kitchen' as postulated by Hofmeister, in which, among other things, enzymes with very different pH optima have to act har-