HUMAN ENGINEERING RESEARCH AND THE DEFENCE SERVICES

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ABSTRACT

The Scope and importance of Human Engineering Research in general and its immediate applicability and utility to the Defence Services in particular have been discussed in this paper.

Introduction

Although finance ministers of governments regard defence expenditure as essentially a non-productive outlay, scientists have reasons to be grateful to military authorities for the boost up it gives to scientific research in diverse areas. To take the example of psychology itself, World War I stimulated the development of mental testing techniques for purposes of personnel selection as well as study of human factors responsible for decrement in industrial productivity or increase in fatigue. World War II has similarly been responsible for many new developments. In psychology one needs mention only two areas—the area of group morale (both of civilian and army groups), human relations and leadership on the one hand and human engineering problems on the other.

World War II has been called a war of technologies where machines played a much greater role in its conduct than in earlier conflicts. On the one hand machines became more numerous and complicated while on the other, the personnel using these were, due to the exigencies of a total war, mostly of average capabilities, very often not completely trained, frequently shifted and mostly functioning under stressful and fatiguing conditions. The need for devising machines with simple information giving devices and controls requiring non-complicated manoeuvering became apparent. These problems of equipment design very soon led to the collaboration of the experimental psychologist with the physicist, the engineer, and the physiologists, over design of such things as instrument dials, radar scope faces, aircraft cockpits, simulator training devices etc. This collaboration led to the development of a new area of research, human engineering or human factor engineering.

Human engineering tends to look upon the machine and the operative as together constituting one single unified system—the man-machine system. It believes that for getting maximum work out of this system the design of the machine should be congruent with the psychological and physiological characteristics of the operative. To the extent that this congruence has been achieved will depend the efficiency of the system as judged by the criteria of speed, accuracy and quality of performance and comfort and safety of the operator. Thus McCormick[1] defines human engineering as "the adaptation of human tasks and working environment to the sensory, perceptual, mental, physical and other attributes of people".

Human engineering research is essentially a cooperative endeavour between such professions as industrial engineering, mechanical engineering, electrical engineering, physics, physiology, psychology, statistics, etc. The psychologist's contributions to this are the knowledge he can impart regarding the human's process of obtaining information, making decisions and acting upon these decisions while he is performing a task. He contributes his specialised knowledge regarding the human senses, their limits and discriminatory powers, regarding the decision-making processes, especially under conflicting and stressful situations and the central adjustive mechanisms involved therein, more particularly the learning process, and finally regarding the characteristics of motor skill required for various tasks and the extent to which these are affected by fatigue or stress. More specifically, this work has been of the following nature: (*i*) appraisal or testing of new equipment designs by comparing them to existing equipment or examining it in terms of known principles of design; (*ii*) determination of optimal methods of work for existing equipment; (*iii*) design and development of new equipment; (*iv*) design and classification of tasks; and (*v*) design of man-machine systems involving determination of number of equipment components and optimum arrangement of men and machines. The contributions made by psychology in this area have been important enough to lead to the general acceptance today of the principle that in practice, equipment design and operating principles should be based on psychological data.

Psychological research in equipment design has been known by various names such as : applied experimental psychology, applied psycho-physiology, applied psycho-physics, bio-technology, psycho-technology, human factor in equipment design, human engineering, human factor engineering and engineering psychology. Two most commonly accepted nomenclature for this branch of psychology today are applied experimental psychology and engineering psychology. Many psychologists prefer this latter term and use engineering psychology and equipment-design research synonymously (for example, Fitts—1951)[2]. Engineering psychology is an adequate expression and in keeping with conventional nomenclatures designating other branches of psychology like industrial psychology, clinical psychology, social psychology, etc. Adoption of the term engineering psychology to mean that branch of psychology which deals with psychological facts and principles of significance for equipment design seems therefore to be justified, both on grounds of logic and convention.

Methods

Before examining the contributions of psychology to human engineering research, a rapid survey of the research methods commonly used by psychologists in this field may be made. Human engineering (or engineering or applied experimental psychology) uses basically the same methods as of experimental psychology. However, problems here are so varied that new techniques as well as modifications of standard methods are being constantly devised. Here little can be said except enumerating some of the more important methods.

There are basically two methods of research—(*i*) the survey method and its modifications which are largely used for identification, analysis and definition of problems for experimental work and (*ii*) the experimental method designed to test the efficiency of a certain set up (e.g., an aircraft attitude indicator) according to some criteria or in a mere theoretical context, to determine relations between variables.

The survey method takes numerous shapes. There is the *activity-sampling technique* which is used for analysing activities of men engaged in complex activities. For example, a recording of activities of aerial navigators at 5-second intervals during flight gives an idea as to how much time can be saved by devising new machines and revised operating procedures. The *critical-incident technique* is another method where detailed analysis is made of critical incidents with the object of detecting sources of errors leading to the development of such incidents. A classic example of this technique is seen in a study by Fitts and Jones[3] on errors of aircraft pilots in responding to insrtuments and signals. Each of 624 pilots were asked (through direct interviews or questionnaires) whether he had ever made or seen any one else make "an error in reading or interpreting an aircraft instrument, detecting a signal or understanding instructions" and if so, to describe these. The results for instrument reading errors are given below:

Classification of 270 Errors Made by Aircraft Pilots in Responding to Instruments and Signals

Nature of Error	Frequency (in %)
1. Misinterpreting multi-revolution instruments	18
2. Misinterpreting direction of indicator movement (reversal errors)	17
3. Misinterpreting visual and auditory signals	14
4. Legibility errors	14
4. Substitution errors (failing to identify a display) ..	13
6. Using an inoperative instrument	9
7. Misinterpreting scale values	6
8. Errors due to illusions	5
9. Omitting the reading of an instrument	4

One of the most important finding of the above study was the information that the three pointer altimeter was about the most difficult instrument to read and that it contributed to a large number of critical incidents. This finding has stimulated a very large number of experimental studies on modified types of altimeter.

Another important method used is the *analysis of errors* in equipment use. Errors in any man-machine system, for example, a radar in use, are compared with the error of the machine (the radar) and the error of the operator. The object of error analysis is to isolate and evaluate the sources of error in the system. In connection with error analysis two points may be mentioned.

Firstly, an important and very useful distinction is made between constant errors and variable errors. A simple illustration of the usefulness of this distinction is errors committed by two riflemen in target shooting, where one person places his ten shots all around the central area (large variable error, small constant error) and the other places them very near to each other but away from the centre (large constant error). Constant errors usually mean that the controls are at the wrong level (the second rifleman will improve if his sights are adjusted appropriately, but not the first who is inconsistent and unsteady). Variable errors are, however, more important for these are "the true indicators of the inherent instability or inaccuracy of a system....The reduction of these annoying variable errors constitute one major objective of engineering psychology"[4].

Secondly, it has also been seen from a large number of experimental and mathematical studies that the overall variance of error in a man-machine system is "equal to the sum of the variances of the error contributed by individual parts of the system", the errors of the component parts being taken as uncorrelated. Actually, the contribution towards the total error by any component increases quadratically with its relative size. To take the example given by Chapanis[4] (op. cit.), if the human error in operating a radar remote indicator is 20 yards and the error of the machine 10 yards (in terms of standard deviation), the total variable error of the system is $\sqrt{10^2+20^2}=22\cdot36$ yards. In other words, the error of the machine has only added 2·36 yards to the 20 yards variable error of the man. Therefore, the practical conclusion is that since it is the addition of squares of errors and not of simple errors that make up the total error of the system, it is always more economical to attack the larger source of error, since even the complete removal of the smaller source may not make much difference to the accuracy of the system. The method of error analysis, a statistical method basically, then allows analysis of errors in complex man-machine systems in terms of errors of component parts and thus indicates where corrective actions will be most useful.

Finally, a large number of human engineering studies are made in accordance with the well-known experimental methods of psychology. Most of the studies having to do with the human senses use traditional psycho-physical methods. Mention may be made of a study by Goldscheider and quoted by Geldard[5] on sensitivity of joints of the human body to movements, a problem of considerable interest to equipment designers. Goldscheider found that of the nine joints tested, the shoulder was the most sensitive (minimum detactable displacemet being 0·22 to 0·42 degree at a speed of 0·3 deg./sec.); the wrist and kunckle of the index finger were almost equally sensitive (0·26-0·42 degree and 0·34-0·43 degree respectively); the ankle had a higher threshold of 1·15-1·30 degrees displacement.

Experiments both with highly complicated apparatus as well as those requiring only paper and pencils are conducted for study of problems in this field. For example, most studies dealing with legibility of dials as determined by different scale lengths, scale graduations, dial sizes etc. conducted by Kappauf and others use simple printed materials. Many of these do not even require a stop watch, although printing accuracy (of different dial faces etc.) demanded is very high. In contrast, other studies, especially those that have to do with analysis of motor performance sometimes require complicated apparatus. Reference may be made to a study of stimulus-response compatibility and stress effects in a one-dimensional tracking task conducted by the author[6]. The study required a one-dimensional continuous electronic compensatory tracking apparatus in the form of a voltmeter with reversible control-pointer relationships and a set of three computer amplifiers for recording the subject's integrated absolute error score. Other studies on human performance like tracking, on design of displays etc. also require complicated electronic apparatus.

For investigators in India, the cost and availability of complicated equipment are obvious problems. However, it should be remembered that: (*i*) studies may be made even with very simple equipment, and sometimes only with paper and pencils; and (*ii*) the value of research results depends also on factors other than the complexity of equipment used, such as the adequacy of the experimental design and control of extraneous vitiating factors.

Some Research Areas

Human engineering, as an applied branch of knowledge, is thus largely interested in improved equipment design and operational techniques with the object of increasing the efficiency of the man-machine system and the safety and comfort of the operator. Its activities are partly professional and largely scientific. The professional activities find major expression in attempts at making available to the engineer and other design technicians pertinent psychological data relating to the operators of the equipment. This is done through publication of handbooks on human engineering data (*e.g.* Handbook of Human Engineering Data—1951)[7] and a number of professional journals.

The scientific activities of the human engineer have their theoretical base largely in experimental psychology. The very large amount of data collected by psychologists on the human senses, especially vision and audition, ever since the days of Wundt give the human engineer a solid body of data which he can apply. Besides these, the research techniques of experimental psychology are also used for solution of specific design problems.

Equipment design work can be over problems which may have no direct significance for the defence services. For example, whether the handle of a motor car should be pushed down or pulled up to open it is one such problem. The first alternative claims ease of operation while the second claims greater safety. Automobile manufacturers take their choice of either alternative indiscriminately. A simple investigation, especially with reference to general motor habits of people can lead to the adoption of a standardised procedure by all manufacturers and save some confusion on the part of the car users. This simple problem of door handles however immediately assumes great significance if the context is changed from the automobile door to the emergency exit opening in a passenger carrying air-plane. The extreme anxiety and stress under which people will be required to operate the emergency exit make it essential that the mechanism should function in the 'natural' or expected manner, that is, in accordance with the population stereo-type. Other examples of suitable human engineering problems in civilian life are design of road signs for vehicle drivers, design of dial faces for watches, clocks meters and other displays used in industrial machineries, design of type faces for books, journals, newspapers, etc. for greater legibility, design of artificial limbs for amputees, etc. In general, such industries as the automobile, radio, home appliances, transportation etc. are likely to provide interesting design problems to the applied experimental psychologist on an increasing scale (see, for example Blum—1952 in this connection)[8].

The rapid advance of human engineering and its present day importance is however due to the contributions it has made towards defence problems. Fitts[9] summarises the general objectives of these studies as two fold: (*a*) to provide qualitative data on human performance characteristics, for populations of people, as a function of task variables, and (*b*) to provide measures of independent and dependent variables which will permit quantitative specification of the levels of reliability, operatability, safety, training costs, or other performance criteria of interest for machine and systems design. A task variable is defined as a property of the stimulus, the response or of the simulated machine and which affects the nature of the task to be performed by a human operator. It is this study of characteristics of response or stimulus or of the machine, and their interaction with reference to performance, safety and comfort of the operator that cover the major group of studies in human engineering or engineering psychology. The other objective mentioned by Fitts [9] has reference primarily to development of valid research methods and measures.

An examination of individual studies will show that engineering psychology has made extensive investigations into the nature of the stimulus as well as the characteristics of the response. Studies on central adjustive mechanisms have been comparatively fewer. Stimuli belonging to different sense modalities, more especially vision, audition, touch, kinesthesis and other proprioceptive senses have been studied. Studies on vision have been the maximum inspite of its being the most complicated of the human senses. This is so because man is largely a visual animal and he gets the maximum amount of information about his environment via this sense. For example, an analysis of the instruments used by pilots in a 4-engined naval aircraft showed that 88 per cent of the controls were operated by the pilot on the basis of visual cues.

Below are discussed briefly some of the problems studied by psychologists in the area of equipment design.

(*i*) *Vision: Visibility and Legibility Problems*:

A display is any device that is used for presenting information to the human. It can be visual, auditory, tactual, etc. One function of a visual display is to enable the human observer to detect a certain visual cue; for example detection of a blip on the radar scope. On the other hand, it may involve not only detection of the stimulus object but also its identification—for example, identification of an aircraft from the patterning of its markings. In engineering psychology more studies have been done on legibility problems involving identification questions than on visibility problems which largely concerns detectability of visual cues. Some direct use of psychological principles in vision has however been made for increasing visibility or detectability of objects. The spread of a yellow colouring material on the blue sea surface for increasing the detectability of a 'ditched' pilot is a case in point.

In Radio Detection And Ranging (RADAR) the problem of visibility of signals which are very often weak have received considerable attention. The radar signal which appears as a bright spot or 'pip' on a cathode-ray tube (CRT) has been studied for detectability effects of such factors as its brightness, contrast with background illumination and size. For example, it has been seen that low contrast pips attain maximum detectability when the background brightness of the CRT is about 0·1 foot lambert. When the CRT face is dark or only moderately bright, dim targets are better discriminated from an eye distance of 6 inches rather than 24 inches. However, when the discrimination is to be done against a high noise background (random brightness variations on CRT face), the detectability problem is transformed into a pattern identification problem and the above observations on optimal eye distance does not hold. Detection of change in velocity of a moving spot on the CRT is another matter that has received some attention. For example, it has been noted that the just noticeable change in velocity of a moving object bears a constant relation (within limits) to the original velocity with which it has been moving. On the average and under optimal conditions, the change can be detected if it is about 12 per cent of the initial velocity. Psychologists will recognise this as the familiar phenomenon described by Weber's Law.

Another interesting developmental work on information chanelling by a CRT has been on the question of whether three parameters of information can be presented on a two-dimensional surface. This point assumes particular significance for air-traffic controllers who have to guide planes in the air on the basis of their range or distance, altitude and azimuth or direction of flight. Experiments are being conducted with displays where two sets of information are given with reference to a polar or rectangular grid system on the CRT face and encoding the third dimension, for example, the range or the altitude, through changes on the image size itself. For example, a large image may indicate a near range or low altitude as the case may be. This depiction of nearness by means of a larger object size, it may be noted, is in conformity with our ordinary visual experience. Apropos the radar system for guiding planes into airports in blind landings, the investigations into methods by which the operator's tendency to over-estimate the amount of deviation of the aircraft from the glide path as a result of perspective illusion may be mentioned. The lending strip was represented on the centre of the scope as a triangle, thus leading the radar operators to increasingly exaggerate the aircraft's deviation from the centre as it approached the apex of the triangle. The perspective illusion and resulting over-estimation was completely eliminated once a series of extra reference lines, parallel to the glide path, were introduced on the display.

In modern machines, the operator tends to get fewer and fewer information directly through his senses. He has to depend on displays of various types for the necessary information. Comparison of a simple Brownie Box Camera and a modern expensive amateur's camera will bring out this difference although the basic function all camera bodies serve is simply the control of the amount of light rays impinging on the photographic film. Since most of the information is received by us through dials of different types, these have come in for a large number of studies. The problem of displays like dials is basically a legibility problem. These require recognition and identification of the symbols which provide a measure of certain variables.

Dials are used for one of three purposes: (*i*) for quantitative reading; (*ii*) for qualitative reading and (*iii*) for check reading. In quantitative readings dials are used for determining the actual numerical value of something. The speedometer of a motor car, the dial on a weighing machine, the altimeter in an airplane, the household electric meter are all dials of this type. Sometimes dials are required to indicate only whether an instrument is functioning in the manner required. In an automobile, the driver is not interested in knowing the exact temperature of the engine. He will be happy if he knows whether it is within normal range or beyond it. Thus the temperature gauge in the car is a qualitative display where the indicator indicates the temperature not in numerical values, but in terms of deviations from the permissible limit. Dials used for check reading indicate whether an instrument is functioning or not. The pointer on a radio set which indicates whether the set is 'on' or 'off' serves a check reading purpose.

Dials have been studied for common errors. One study of pilot errors reported above showed that the three-pointer altimeter was perhaps the most difficult aircraft instrument to read correctly. Also studies have been made of various physical characteristics of dials for optimal measures. For example, efficiency of different dial shapes has been enquired into. In a study by Sleight[10] it was found that percentage of errors for different dial shapes (percentage of incorrect reading out of a total of 1020 readings for each dial shape, exposure time being 0·12 second each) were as follows:—

Dial Type	Per cent, of incorrect readings
Vertical linear dial, moving pointer	35·5
Horizontal linear dial, moving pointer	27·5
Semi-circular dial, rotating pointer	16·6
Circular dial, rotating pointer	10·9
Open-window, fixed pointer, rotating scale with part of scale exposed only	0·5

The open-window shape was found to give the least number of errors in readings, possibly because here the indicator position is fixed and no secondary eye movements or search behaviour are required. However displays should not only be easy to read quantitatively but should also indicate to the observer the rate and direction of change of a variable from moment to moment to facilitate motor response. For example, the pilot needs to know not only the height of the plane at a particular time but also, especially when he is coming down or taking off, how fast and in what way his height is changing. Judged thus, direct-reading displays where the appropriate numerical symbol is directly exposed is less advantageous than scale-and-pointer combinations and amongst the latter, the open-window less efficient than the other shapes.

Scale units and markings have also come in for numerous studies. What should be the optimal distance between the minor markings (the smallest unit to be read on the dial) should there be individual markers for the smallest unit or are major markers only enough, with the subject interpolating between markers? Different numerical progressions in scale design for accuracy of scale reading, design of scale markers, their thickness, position, etc. are some of the other topics studied. Below are given a few interesting results and which are likely to be useful for dial designers:

(1) Reading is best where the smallest unit is represented on the scale by about 0·05 inch to 1·0 inch.

(2) Where time for reading is adequate, smallest unit to be read should be represented by individual markers, preferably numbered.

(3) Where reading time is limited, fewer markers should be used, with the observer reading the exact value by interpolation between these.

(4) Reading error is influenced more by the major scale divisions used than by the value of the minor scale divisions. Numbering of divisions in terms of 1s, 2s, 5s, and 10s can be read better than those with 3s, 4s and 8s. The ideal scale design is one with major numbered graduation mark at each ten and minor unnumbered division mark at each unit.

(5) Reading is facilitated if the numerals are horizontal to the line of sight of the reader.

(6) Markings of numerals and capital letters are best when (*a*) ratio of stroke width to its height is between 1 : 6 to 1 : 8 and (*b*) the width of the letter or number is two-third its height or greater.

It must be mentioned in parenthesis that the above findings do not hold for dials of all types, for all purposes and even for all individuals. Interaction between variables, the ever-present bane of all biological sciences, befuddles the issues. Some of these possible interactions have been studied; for example, the interactions between time factor and different physical characteristics of the display. Some of these have not been studied; for example, interaction of stress (on the individual) and characteristics of the display with reference to accuracy of information received from display. The little knowledge we have shows that under stress situations, operators are likely to regress to more primitive and earlier learnt behaviour patterns. This implies that there are some widely held and old established perceptual and motor habits of the nature of stereotypes and design of displays should conform to these to avoid confusion under stress. Whether a response to a particular stimulus is a population stereotype is determined by its frequency of occurrence in the general population. It is in conformity with this principle that psychologists suggest that on a circular dial with positive numbers, clockwise movement of the pointer should indicate an increase in the value measured and counter-clockwise should indicate a decrease. If pointer is fixed and the dial face moves, counter-clockwise movement of the dial face should indicate increase. Similarly, movement of the pointer to the right (for a horizontal dial) and upward (for a vertical dial) should indicate increase and conversely. However, this phenomenon of population stereotypes needs further studies. For example, in a horizontal dial is it natural for a Persian, accustomed to move from right to left in writing, to interpret a movement of the pointer to the right as indicative of increase in value?

The other problem of individual differences (as distinct from group or population characteristics) is accented by the finding of significant interactions between (*i*) subjects and dial sizes and (*ii*) subjects and different scales. To quote Chapanis et al.[4] (p. 141): "This is disturbing because it means that all people do not give the fewest errors with the same size of dial or the same kind of scale. We cannot tell why this is at the present time, but it means that we may have a little trouble trying to work up some generalizations about the best kind of dials for all people". What is true for dials may very well be true for other devices and machineries. These are exactly the problems that require careful attention from discriminating research workers.

Another problem much neglected by psychologists is one of mental set. We have raised this problem here since we would like to illustrate it with reference to displays that are used for giving directional cues. Consider the case of the aircraft pilot who has to change over from 'contact' flying to 'instrumental' flying. In the former, he looks out at the fixed horizon (except when flying at very low altitude) and perceives the banking, climbing, turning, etc. of his aircraft against it. When he changes over to 'instrument' flying and if he has an aircraft attitude indicator of the 'inside-out' type, he would see the mark on the display representing his aircraft in a fixed position, whereas the line representing the horizon swings round in response to banks, etc. of his plane. The relation between the stimulus and the corrective movement of the pilot when flying under the 'external reference principle' is opposite to the one obtaining in flight conditions under "aircraft reference principle". Consequently, in the initial moments of change-over from contact to instrumental flying the pilot, on account of the difficulty in changing his mental set from one principle to the other, may commit reversal errors by moving the controls in the wrong direction. This phenomenon has been experimentally substantiated to some extent by Warrick[11] in an experiment with two control-display set-ups, one in which the rotation of controls in one direction led to the movement of the controlled object in the same direction and another in which the relation was opposite. When Warrick used a mixed arrangement where the subject sometimes had to operate the apparatus under one condition, and sometimes under the other, thus requiring a change of set on the part of the operator during the task, performance was poorer than it was under either of the two homogeneous conditions.

This problem of mental set has been discussed in detail by Dashiell[12] who calls it a neglected fourth dimension of psychological research. He maintains that mental set so shown itself in different situations and experimental set-ups in an all-pervasive manner. It is seen in reaction time experiments (fore-period set and magnitude of RT), in word association tests (inducement of set for 'opposites', 'subordinates', etc.), in work curves (warming up), in delayed reaction experiments, in 'sets' in reproduction of ambiguous figures, etc. A set, in this sense, is a state of readiness or expectancy or excitation background. Many of the errors in carrying out corrective responses to stimulus received may be traced to presence of two contrary sets, inhibiting each other or in some way preventing a smooth innervation of the necessary musclegroups. Upto now, unfortunately, neither physiology nor neurology is sufficiently advanced to give us an adequate understanding of this phenomenon that may prove of practical or applied value. In view of the importance of set in performance, it is appropriate that behavioural scientists should take up a study of this. To the best of our knowledge, no systematic work is being done on this problem.

(ii) Audition : Intelligibility of Speech and of Auditory Signals

In audition the greatest amount of research has been done in the field of speech communication and use of different tonal signalling systems. A brief account of some findings in these areas are given below.

In quiet, speech intelligibility increases with its intensity. Intelligibility is very high when speech intensity is between 30 to 80 decibels; and low above and below these ; it is maximum at 60 db. which can be regarded as the optimal intensity for intelligibility.

Experiments have been conducted on the extent of speech interference at different intensities of noise. Below is given a summary of maximum tolerable noise levels under which speech communications of different types can be maintained with conventional vocabulary (adapted from McCormick[1] Table 7-2, p. 164):

Upper noise limits (in db.)	Voice level and distance	Nature of possible communication
45	Normal voice at 10 ft. ..	Relaxed coversation.
55	Normal voice at 3 ft.; raised voice at 6 ft.; very loud voice at 12 ft.	Continuous communication in work areas.
65	Raised voice at 2 ft.; very loud voice at 4 ft.; shouting at 8 ft.	Intermittent communication.
75	Very loud voice at 1 ft.; shouting at 2—3 ft.	Minimal communication (like for danger signals).

Speaking over the telephone is reported to be 'Satisfactory' in a noise of less than 60 db, 'Difficult' in 60—75 db noise levels and 'Impossible' when it goes above 75 db.

However, articulation score is reasonably constant as long as the speech to noise ratio is constant, regardless of the overall intensity of speech. For any S/N ratio, there is an optimal speech intensity for best intelligibility. These values have been experimentally determined; e.g., for a S/N ratio of +5 db, a speech level of 70 db shall have maximum intelligibility. A corollary to this is that sometimes, for a given S/N ratio, a lowering of the speech intensity may actually improve intelligibility. This is why ear plugs that cut down intensities of speech and noise (but keep the S/N ratio constant) may sometimes improve intelligibility.

Masking of speech by noise is more effective than by tones of high or low frequencies only. Some important facts regarding masking by noise are summarised below:

(1) Maximum masking of speech is effected by high intensity noise (e.g., of 113 db) of low frequencies (below 700 cps); masking effect of high frequencies (e.g. above 2000 cps) is relatively small.

(2) With low intensity noises masking is high if these are composed of high frequencies (above 1000 cps).

(3) Of these two types of noise, of high intensity low frequencies and of low intensity high frequencies, the former has much more masking power than the latter. However, speech is by far the most effective masker of speech, since these have similar frequency spectra. Jamming of broadcast speech is thus most effectively done by several voices of high intensity maintaining a continuous outpouring.

The above deals with some characteristics of noise in masking speech and making intelligent conversations difficult. Noises do not usually lead to continual interruption of speech, that is, time distortion. Any way, such interruptions cut down intelligibility appreciably only when it is at a rate slower than 1/8 second. This is because most speech-sounds last for about 1/8 second or less and only for interruptions longer than 1/8 second whole speech-sounds will be missed and intelligibility appreciably reduced.

Use of tonal signals and the problem of discriminating between or recognising tones is an important problem for aviationists, sonar operators etc. where all or a substantial amount of information they get is channeled through the sense of hearing. Use of radio-range signals for guiding an aircraft along a particular air-lane is an important example. In some countries, two radio beams of 1020 cps are used, one transmitting the code letter A (dot—dash) and the other N (dash—dot). The two beams are tuned on and off intermittently in such a fashion that the pilot, so long as he is moving along his path, will hear not two but none steady tone. If the plane is to the left or right of the path, the pilot hears the A or N. Obviously then, the pilot's awareness that he is flying the right course will depend on his ability to discriminate between auditory signals. The poorer his discriminatory power, the wider will be the zone of the steady tone, and since it will mean his less strict adherence to the given path, the nearer he is likely to be to an aircraft going in the opposite direction.

Several factors have been found to be important in man's discrimination of tones. For example, a tone must have a certain minimum duration to be recognised as a tone and not a click (about 10 milliseconds for a 8000 cps tone). Ordinarily we should get at least 3 complete cycles of the tone for recognition. The DL for pitch which measures our ability to note changes in the pitch of a tone unfortunately varies with both intensity as well as duration of tones. For example, $\triangle f/f$ is ·0036 for a tone of 1000 cps and 30—50 db intensity, the minimal Weber fraction for a pitch being ·0017 and this for a tone of 2000 cps at 70 db intensity. The exact number of discriminable frequencies between the highest and the lowest audible tones is somewhat controversial and estimates vary from 1500 to 11,000. Studies on these and similar topics are of obvious military significance for development and maintenance of effective communication systems.

(iii) *Tactual Devices : Shape and Size Coding*

Many of our skilled movements are guided by touch. Attempts have been made therefore to provide information to the individual not only through visual and auditory channels but also through tactual devices. One of the first attempts in this direction has been the use of shape-coded control knobs. This arrangement involves use of different and distinctly shaped knobs on different control handles, levers, etc. If the operator changes from one arrangement of controls to another, the confusion arising from his original position habits will be lessened because of his ability to recognise the controls by touch. The study by Jenkins wherein 25 differently shaped knobs were designed, and on the basis of data obtained from 40 subjects, divided into two sets of 8 each such that knobs within each group are rarely confused with one another, is now well-known to applied experimental psychologists. Following this and similar studies, the U.S. Air Force has developed ten knobs that have been standardised for use on their cockpit controls.

Size coding and also colour coding of control knobs have been made. But their effectiveness is limited. It is easier to recognise more shapes of the same size than different sizes of the same shape. Usefulness of colour coding is also restricted in that it requires the operator to look at the controls rather than recognise these by touch alone.

One interesting series of studies in this area has been over an attempt to develop an alpha-numeric code for transmitting normal language message through the skin Geldard[13]. The problem was to find out how many tactile stimulus dimensions could be identified on an absolute basis (not comparative judgements which come easier to humans) by the human skin. Geldard tried in one experiment five different locations (on the chest) of the tactile stimulation, three levels of stimulus intensity and three levels of stimulus duration, and thus got $5 \times 3 \times 3 = 45$ discrete symbols or alphabets. It seems that language messages sent through the skin to a trained 'reader' by means of these 45 symbols or 'alphabets' could be received by him at a rate substantially higher than of a Morse code operator.

(iv) Human Motor Response and Design of Controls

It is only recently being realised by equipment designers that efficient operation of equipment depends also on the speed and accuracy with which the operator can make the necessary movements. This has led to an increasing number of studies on characteristics of human motor responses and design of controls.

Human motor responses are ordinarily classified under the following heads :

(1) Static reactions in which a bodily member is held for a length of time in a fixed position. Here maintenance of the limb in position is the main task. Since very few controls require being held in a constant position, static reactions are not of great importance to equipment designers. Efficiency of this movement is measured in terms of muscle tremors and drifts.

(2) Positioning reactions which refer to movement of a limb from a fixed resting place to a specified position in space.

(3) Movement reactions which are movements of a bodily member at a given speed, in a given direction and along a given course.

In the placement of controls, findings from experiments on blind positioning reactions where the subject is required to locate objects in space without looking at them have been very helpful. For example, it has been found that for maximum accuracy and uniformity, such controls should be placed 4 to 15 inches from the body; for low relative error, the movement should be away from the body; however, if low variability is important, the movement should be towards the body. Another very important study on positioning movements relating to location of controls without use of the eyes was made by Fits[3] and reported in 1947. The experiment required the subject to react blindly for targets positioned in three tiers around him, the middle tier being at shoulder level and the two other tiers being above and below it. In each tier the targets ranged from 135° left to 135° right of the subject. It was seen from this experiment that accuracy of blind positioning movement is best directly in front of the subject and below shoulder height. The positions around to the side and slightly behind the subject had the highest error scores. Also accuracy was least for targets in the upper tier and most for those in the lowest tier below the shoulder level. More specifically, the conclusion was that controls in the preferred front area of the pilot or operator should be placed about 6 to 8 inches apart and those at the back and sides 12 to 16 inches apart for maximum accuracy in blind location.

Movement reactions, which are the most complex and also numerous in machine operations have been classified into four groups : (*i*) discrete single unitary movements; (*ii*) repetitive movements (e.g., tapping and cranking); (*iii*) serial movements (e.g., operating the keyboard of a typewriter); and (*iv*) continuous movements (e.g., operating the steering wheel of a car, tracking targets with guns etc.). Efficiency of these various types of movements have been studied with reference to four basic factors of reaction time, speed, force and precision.

Numerous studies have been made on different aspects of movement reactions, particularly of continuous motor trackings. For example, Corrigan and Brogden[14] were interested in finding out the accuracy of continuous movements in different directions. In the experimental set up, the direction of the tracking path was given 24 different angles. It was found that continuous hand movements are most accurate from lower left to upper right or *vice versa* and least accurate from lower right to upper left or *vice versa*. In another experiment the object was to study how temporary withholding of information about the input (target) or the feedback signal (cursor) affect performance in a pursuit tracking operation. It was found that performance is affected more if the input information is interrupted (e.g., the target on the oscilloscope that is being followed is not shown on the display continuously) rather than the feedback signal (i.e., the cursor which responds to the subject's manipulations is not shown continuously).

Detailed analysis of the tracking task has brought into relief its several features. Some of these are : (1) a continuous task performance can be broken up into a series of discrete movements; (2) each discrete movement is predetermined by the subjects set; (3) these movements are triggered off in units and are not under continuous visual control of the subject; (4) once a movement is started, it is not changeable till a certain minimum time has elapsed. This last point is relevant to the concept of psychological refractory period developed at the Cambridge Psychological Laboratory. This concept implies that a primary response initiated by a stimulus *S* cannot be changed or followed by a different response to a second stimulus, unless at least a period of about 0·1 second has elapsed since the start of the first response.

Recommendations regarding design and location of controls based on characteristics of the human motor response have also been made. These are to be taken in conjunction with requirements for engineering efficiency. Such factors like types of control (contact, selector or adjustive control), direction of movement of controls, force and amplitude required by control movements, bodily part used for operation of controls, control-display compatibility, lag and oscillation in control systems, linearity of controls and displays, distinguishability of controls etc. have been studied and valuable and useful conclusions arrived at.

Concluding Remarks

Inspite of the above rapid review of discrete findings in this latest branch of psychology, it needs reiteration that engineering psychology has a point of view, a way of looking at things which determines its approach, methods and experimental design. This point of view is that the man and the machine constitute a system and operational efficiency of the system depends on the extent to which the two components are congruent with each other. This problem assumes a greater importance in view of the rapid progress of automatisation, especially control and computor automation (Ganguli—1958)[15]. Automation, like its predecessor the powered engine, is bringing about a gradual change in the relative functions of the man and machine. On the basis of our existing knowledge we can say that the machine will take up more and more of the following functions by virtue of its superiority over man (adapted from McCormick—1957; p. 421)[1].

I Quick response to control signals;
II Application of great force smoothly and quickly;
III Performance of repetitive routine tasks;
IV Storing information briefly and then erasing it completely;
V Rapid computations;
VI Performing many different functions simultaneously.

Humans seem to surpass existing machines in the following functions and are therefore likely to continue doing them:

I Detect small amounts of light or sound;
II Receive and organise patterns of light or sound;
III Improvise and use flexible procedures;
IV Store large amounts of information for long periods and recall relevant facts at the appropriate time;
V Reason inductively;
VI Execute judgements;
VII Develop concepts and create methods.

To say the same things somewhat differently, the human is very good in making comparative judgements involving matching, judging, etc. (but not so good for absolute judgements), in perceiving relations and in selective attention to stimuli. For example, still no machine has been built for inspection work, reconnaissance work, etc. He is good in long-term and not so much in short-term memory, can store much more information than any computor and possesses the characteristic of random access to these. Man has the unique quality of possessing a language and its motor response system is good for carrying out complex patterns of movements. Man is also capable of inductive reasoning and is a highly versatile organism capable of doing many things and striving for many goals. Machines will more and more take up the task of alerting (warning systems), of making absolute judgements, of doing work involving short term memory and strong and rapid use of force.

Gradually, on account of the technological advancement, the skill thus required by man will shift from motor to 'perceptual' (ability to see and receive information) and 'conceptual' skills (ability to understand the received information and to know 'what to do'). Thus man will be more and more a guiding and directing agent rather than a doing agent. This shift in relative duties will make the question of adjustment between man and machine more and more central to equipment design. Human engineering approach together with its contributory sciences like experimental psychology and physiology will attain greater prominence.

Another point that needs mention is that research on personality characteristics and human abilities with reference to equipment design though of no small interest, has not received as much attention as it deserves. Eysenck[16] has reported his findings on the relation between neurosis and human abilities from a study of several thousand neurotic and normal soldiers. He concludes that neurotics tend to be rather below average in intelligence for speeded as well as non-speeded tests, have somewhat inferior sensory acuity (visual and auditory) and especially dark vision, and show extreme perseveration (high and low) and greater perceptual rigidity. Further, their exercise response and static equilibrium are significantly poorer than among normal controls, as also the quality of their autonomic responses. Now, if we accept Fraser's[17] figure of 10 per cent of industrial population as suffering from definite neurosis, the question of personality disorder, abilities and setting up of standards for equipment design deserves some attention.

Influence of stress on performance is another factor that has been comparatively neglected. Stress may be due to environmental factors, task factors as well as organic factors. A very strong emotion, for example, anger, raises the level of activation of the organism, behaviour becomes more gross, there is more and more restriction of the sensory field and performance lacks precision (Woodworth and Schlosberg)[18]. A high anxiety level in the individual may be another source of stress that may adversely affect his performance on complex tasks or increase the completion time for these (Sinha and Singh)[19]. Stress may also be due to demands of the work itself. In a study by Ganguli[6] the introduction of a secondary task became a stress-inducing factor and increased the errors in the performance of the tracking task. Finally, stress may be due to adverse environmental conditions relating to heat, noise, lighting etc. Conditions in Indian industries have been studied and reported by K. Subramanyan and N. Majumdar in the Indian Journal of Medical Research, 1951 to 1953. They found that the working environment in Calcutta jute mills was the range of discomfort (above an effective temperature of 80°F) for 65 per cent of the year, in carding sections of cotton mills for 92 to 94 per cent of the year, in printing presses for 50 to 60 per cent of the year and so on. Internal environment of special military machines like a submarine or a tank can be worse and therefore more stress inducing. Unfortunately however the way in which these stress-inducing factors affect performance is not very well understood by us. Obviously more research is needed for designing equipments where performance is as little susceptible to adverse effects of stress as possible.

Engineering Psychology in India

Active research in engineering psychology in particular and human engineering in general in India are limited perhaps to the Defence Science Organisation (e.g., Adiseshiah)[20]. This field is as yet untouched by universities and technical institutes in the country. This is in direct contrast to the situation in advanced countries like U.S.A., where in almost every important university there are psychologists engaged in this type of research for the defence services as well as for industries in cooperation with other scientists and engineers. An important reason for this lack in India may be that equipment design as a distinct branch of technology is still in its infancy here. However as industries develop and the defence services expand, the need for human engineering research is bound to be felt.

One can visualise the type of background data that would be required for a full-fledged equipment design programme in this country. The very first things one would need are certain physical, physiological and psychological measures for different sections of the Indian population. Central and variable measures in the Indian population of factors like body height, weight, arm reach, strength of different muscle groups, vital capacity, special abilities like tapping and cranking, reaction time, intelligence, acuity and discriminatory power of different senses like vision, hearing, kinaesthesis, etc. are of the essence. Without such knowledge, design and mass production of even a simple thing like class room benches is not possible, far less the production of complex items like automobile seats or aircraft cockpits. Since these qualities do not remain static, one would also require to know the change in these as a result of intra- and extra-organic factors like age, accident, temperature, humidity, altitude, nutrition, etc. Such a programme for basic data would necessitate coordinated research by experts in the different biological sciences and it is hoped that Indian universities and specially professional institutes and organisations would take up this work in a systematic manner in conjunction with industries, both civilian and defence.

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