BRITISH MEDICAL JOURNAL

LONDON SATURDAY JUNE 14 1947

THE MEASUREMENT OF HUMAN SKILL*

BY

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The Nature of Skill

Perhaps the beginnings of skill are to be found in the graded response. As has often been pointed out, it is a characteristic of a good many very early and very simple kinds of reaction to be of the "all or none" type. There is some evidence, which will have to be considered later, that a "trigger-like" character of effector response, in which nothing happens until a stimulus exerts a certain "pressure" and nothing more happens even when the stimulus exerts much more "pressure," remains to play a little regarded or understood part in quite complicated expressions of mental and bodily behaviour. But it is certainly the case that most of our everyday actions seem to be more or less accurately graded in amount, direction, duration, and other respects in agreement with corresponding variations in the stimuli required to produce them. And such graded action, however simple it may be, has at least one of the fundamental marks of skill—an effector response is not merely set off by a receptor function but is guided and determined by it. The receptor functions that are important in the case of skilled behaviour, however, are, I think, never those alone which indicate changes in shape or volume of muscle. They are always of that kind which claims to register something that is going on in the outside world. So they come to be particularly identified with the operations of the special senses, and especially of those distance receptors which are the basis of tremendous development of the central nervous system. Skill, then, whether bodily or mental, has from the beginning this character of being in touch with demands which come from the outside world. This is what gives it its strong cognitive nature and makes it possible to use phrases such as the one coined by Elliot Smith: "the intellectual respectability of muscular skill."

Whenever we talk of skilled behaviour, however, we mean much more than this simple and basic fact of detailed determination by receptor function. We mean behaviour in which a good many different receptor and effector functions are interlinked, all joined in the pursuit and achievement of some task which, when it is achieved, seems at first sight as if it can be discussed, criticized, evaluated, and even measured in its own right, apart from the means used to bring it about.

Let us consider a few instances of what everybody agrees to call skilled performance. Since it was wartime experience which revived for me a long-standing interest in the nature and conditions of human skill I will begin with two cases which have been a subject of much experiment in recent years.

The bomb-aimer in the aircraft, peering intently through his bomb sight, watches and interprets a series of visual cues coming from successive clusters of landmarks some of which are of predominant importance. From time to time he issues directions to the pilot and receives the answering confirmation. He judges at length that the series has reached its culmination, presses his bomb switch, and the operation, so far as he is concerned, is complete. If the bomb falls within the effective target area the task may be adjudged well and truly done. The visual cues, predetermined and so laid out and seen that one leads to the next and does not merely precede it, may differ every time, though their significant order remains relatively the same. The attendant effector responses may differ also right up to the final pressing of the switch. Yet the criteria of the success or failure of the task seem to remain constant.

The pilot, airborne and flying on his instruments, must be alert to an almost incredibly complex mass of incoming signals—visual, auditory, tactile, thermal, proprioceptive. These, at the appropriate moments, his actions must match. The whole performance, from take-off to landing, is a long-drawn-out interlinkage of receptor and effector functions, forming a veritable series and not merely a succession, each item a step to another step, right to the end. Yet it has often been claimed that an informed observer, sitting by the pilot, knowing nothing, or next to nothing, of the terrific play of his senses and muscles and mind, can criticize, rate, and measure his achievement. More than this is sometimes claimed; for it is said that an observer who never sees either the pilot or his aircraft, but is merely supplied with an objective record of what the machine has done, especially during critical manoeuvres, in the course of its flight, can with reasonable success measure or assess the pilot's skill. Even beyond this, though possibly with some exaggeration, it is often considered that the skill of the pilot can be correctly criticized and judged if nothing more is available than an accurate objective record of the landing.

And we could take any other case of admitted human skill and find that exactly the same sort of fundamental considerations apply. The good player of a quick ball game, the surgeon conducting an operation, the physician arriving at a clinical decision—in each case there is the flow from signals interpreted to action carried out, back to further signals and on again to more action, up to the culminating point of the achievement of the task. From beginning to end the signals and actions form a series, not just a succession. The items in the series have, within wide limits, a fluid order and varying qualities. Moreover, there are always plenty of people—we all do it—who are willing to pronounce a verdict on the achievement alone, sizing it up, placing it in

* The first of two Oliver-Sharpey Lectures given at the Royal College of Physicians of London on Jan. 21.

relation to other achievements of the same sort. Can it be that the measure of skill is really a measure of the achievement which skill attains?

As soon as that question is put difficulties will occur to everybody. If the bomb drops in the effective target area once, and the next fifty times drops outside it, in ordinary speech—which may be fickle, but is generally of some psychological interest—we call it a lucky shot. It is clear that measure by achievement must have a lot of achievements to work on, and even then is statistical only. This is an upshot which is openly accepted, or ought to be, by all those who pin their faith to those measures of skill by tests which have become enormously popular of late. I cannot, within the limits of these lectures, consider this kind of measure, but it is certainly not very satisfying to the experimentally minded, who if they wish to avoid or supplement it are forced back upon studies internal to the skill performance itself.

There appears to be something level and uniform in skill performance which is consistent with considerable variations in skill achievement. W. R. Hammond,* a witness of some merit—to speak mildly—says that his most skilled innings was one which gained him a mere 32 runs. When we search the skill performance to find what these uniform characters are and how we can use them to obtain the measures we want, we can, I think, set the problems into three main groups.

There are, first, problems of the linkage of receptor and effector functions; second, problems of the grouping and stability of the constituent items in the full performance; and finally—for we cannot really get away from the “task”—problems of the relation of achievement to means.

Each of these groups can be approached experimentally. If in attempting to describe this approach I deal in the main with work developed during the last few years in the Cambridge Psychological Laboratory, it is not from any lack of appreciation of significant developments made elsewhere, but for two main reasons. First, I cannot well help knowing more about it myself; secondly, for obvious reasons some of it could not be widely reported before, and may therefore be of greater interest to others.

Linkage of Receptor and Effector Functions in Skill Performance

There is one characteristic which crops up over and over again in descriptions of expert skilled performance. The operator is said to have “all the time in the world to do what he wants.” This has nothing to do with the absolute speed of the constituent movements, bodily or mental. These may be almost incredibly quick, or they may be leisurely and slow. What is impressive is the absence of any appearance of hurry in the whole operation. There is no jerkiness or snatching, no obvious racing to catch up in one part and forced sauntering to make up in another. The “time” that is spoken of is really “timing,” and if we could understand the simple timing mechanisms which the human body and mind must obviously be able to use, and how they work, we should have got some way, at least, towards a measure of degree or level of skill.

Perhaps this is what has made most investigators who have set out to measure skill turn to the classical reaction-time experiment. Considering that every possible skill that can be studied consists of a set of actions and reactions between receptor and effector processes, this seems a sensible thing to do. Yet it must be admitted that not one single investigation of reaction times in the classical manner, however elaborate it has been, has thrown any

important light on the problems of how to achieve a measure of skill.

The technique of the reaction-time experiment was worked out by the Dutch physiologist Donders in the 1860's. It has not been varied in any important respect since then, except in regard to instrumentation, which has of course enormously improved. Donders did not set out, in any sense whatever, to investigate skill. His aim was simply to measure the time elapsing between the presentation of some simple form of stimulus and some single simple muscle response. Naturally and rightly, therefore, he chose responses which, so far as the experimental measure is concerned, literally begin and finish at the same instant. The finger lifted from a morse key may rise an inch or a mile, it makes no difference. In any conceivable form of skill, however, circumstances of this kind do make a tremendous amount of difference. This is because a given movement has to be followed by another and the second has to be spaced correctly in regard to the first. The time we need is the total reaction time, including that required for the full completion of a given movement, and the recovery time which the organism must have in order that a successive movement should be efficiently performed. This recovery time may have to take account of latent effects produced by the original stimulus whether on the receptor or the effector side.

For example, as is well known, it can be experimentally shown that when a muscle is operating against resistance certain latent effects remain, when its operation is completed, which will automatically interfere with a succeeding reaction of that muscle, or muscle group, and perhaps with related muscle groups. More important still, very likely, every constituent action in the case of most psycho-physical skills must grow out of a setting of bodily or mental posture. This posture must be reset before the succeeding movement can be effective.

Timing of Constituent Reactions

It is, I think, vitally important, if we are to understand the simple timing of constituent actions in the continued exercise of skill, to study and determine the normal limits of duration of these latent effects, of after-contraction in the case of muscle, of the after-effects of certain receptor sensory processes, and of the reset of posture required from move to move in almost all forms of bodily and mental skill. Experiments at Cambridge have recently shown, for instance, that where after-contraction is lacking or excessive certain kinds of skill—those involved in piloting aircraft—are learned with difficulty and when learned are easily broken up.

Now there seems to be a considerable amount of evidence which suggests that in general the recovery time for receptor processes is shorter than that required by effector processes. For example, a year or two ago we set out to study some of the phenomena of visual accommodation. The display consisted of a series of Landolt rings, or broken circles, with the gap north, south, east, or west, in relation to the observer. The rings were presented alternately at near and far distance, and a simple four-way switch was designed by which the operator could indicate the assigned position of the gap. The time and duration of appearance of each item in the display were automatically recorded, and similarly the beginning and end of every reaction and the intervals between successive items, both of display and of response. When the operator was fully used to the situation he was allowed to determine his own preferred rate of working. His first response sets up the second stimulus, his second response the third stimulus, and so on. Naturally the preferred rate fluctuated somewhat for a

* *Cricket—My Destiny*. 1946, p. 128. London: Stanley Paul.

given operator, but not by very much. Preferred rates of different operators varied considerably. We now determine the upper tolerance limit of speed for the whole population, taking as our criterion the occurrence, and perhaps recurrence, of half a dozen closely contiguous errors or omissions. In this case, of course, the rate of exposure of the rings is determined by the experimenter. There is some evidence that the upper tolerance limit remains approximately constant for different operators at an increase of speed proportional to the preferred rate. But the most interesting result is that the study of the records shows that when the operator breaks down he is, in almost all cases, trying to respond, not to the circle that is immediately before him, but to the preceding circle, or to the second or third preceding circle. The receptor and effector series have got out of step, the latter lagging behind. We have some evidence that much the same happens in tracking a rapidly moving target, and dealing with radar displays in extremely quick sequence. And, indeed, this only confirms much common observation. In reading, the eye interprets far ahead of the voice, and if an effort is made to read exceedingly swiftly, "by whole paragraphs," as H. G. Wells used to say, it can be effective only if much of the usual effector association is short-circuited or suppressed. Perhaps the case is most striking of all when posture has to be reset. For then it is the accessory movements, of which normally the operator remains totally unconscious, which markedly and obviously go wrong. The footwork, which may settle the whole body balance, lags and sets everything else out of time. It is extremely tempting to suppose that often when this kind of thing happens, and when the operator is struggling to deal with receptor signals which are no longer present to him, these signals have got on to a rapidly accelerating phase in the curve of immediate forgetting. We have evidence in favour of this, but it is not yet conclusive.

Nothing in the whole course of the total reaction time is rigidly set. Like every other measure of human function this turns out to be a measure of range. There are limits, upper and lower, within which the timing can rapidly fluctuate and the essential adaptive spacing of actions still be maintained. Outside those limits only the skill breaks down.

To a psychologist this is singularly interesting, because most of the conditions that determine the extent of the range can at present be dealt with in psychological terms only. This is not always the case. For a simple objective increase of urgency—in speed, for example, or in the resistance opposed to movement—will be met swiftly by an almost reflex-like increase of effort. Skill that is threatening to deteriorate can, paradoxically, often be restored by an objective increase in the difficulty of the situation. Precisely the same effect, however, can be produced, and on a high level more frequently is produced, by definite volition. How this is done still remains largely unknown, but it is certainly in part achieved by the suppression of flourishes which have become uneconomical, though this essentially does not mean that they always are so. That they are not can indeed be seen in the curious circumstance that on the whole it is easier to shorten than to lengthen the customary overall response time. We have many experiments which show that slowing of skill is very hard to tolerate, and I suspect that this is because suppressing flourishes is less difficult than inventing them.

Another condition which can produce shortening of response time is anticipation. Perhaps this is largely responsible for the demonstrated fact that real experts retain their skill under conditions which defeat the beginner or the performer of ordinary ability. For example,

receiving and sending wireless messages at speed can be adversely affected by a steep rise of temperature and humidity. But whereas the upper limit of effective temperature for the average performer comes rather sharply at 83° F. (28.3° C.), the expert continues without serious disturbance for another 17° F. (9.4° C.). Yet the overall response times for all performers remain closely comparable under all ordinary conditions.

Finally, anything that can arrest the speedy decay of immediate memory will tend to lengthen the overall effective response times and keep receptor and effector functions sufficiently in step for long periods. The conditions which promote this seem to be largely on the display side, in the ordering of the signals for skill which have to be dealt with by the senses, and especially the distance senses. A degree of novelty just enough to combat the peripheral processes of adaptation and the central tendencies of habituation is desirable. Little is known about these conditions as yet, but it has become clear that the placing of signals, especially towards the upper and leftward parts of a visual field, their movement and direction of movement, and the utilization of contrast and colour are all of them important.

The Phenomenon of "Lowered Standard"

On the other side, and working all the time towards an increased liability for items in skill behaviour to get awkwardly out of phase one with another, are adaptation and habituation, and something different from both—the curious phenomenon of "lowered standard." Like a lot of other things in behaviour, once this is defined and clarified under experimental control abundant illustrations can be found in everyday experience. This often lays the psychologist under the charge of discovering only what everybody already knows; but that kind of discovery is in fact as important for exact knowledge as any other. We first noticed the case of "lowered standard" when we were studying the kind of deterioration which can be expected to affect the skill of the air pilot who is flying on instruments for long periods without rest. The operation, like that of every other instrument reader, is essentially an exercise in the discrimination—usually the visual discrimination—of alignment and misalignment. The operator must notice the coincidence of a pointer or other indicator with, or its variation from, some mark or member of a series of marks on his instrument. For two reasons it is no use at all taking a measure of absolute visual or other spatial discrimination threshold and deducing anything from that. The observer has to respond not only to the misalignment but to the direction of it. He has not only to notice the appropriate mark on the instrument but to identify it among a number of other marks. It has been known for years that either of these requirements will push up the discrimination threshold, and if the amount of the rise depends at all on the absolute discrimination threshold their functional relations are certainly unknown. On top of this it is still no use allowing for these matters and then getting a measure of effective threshold *outside* of the skill in any succession of isolated graded tests. For within the skill there are always two thresholds—one a measure of what the observer *can* do, and the other of what is treated as *worth* doing. These can, and constantly do, vary quite independently. At the beginning of exercise they normally approximate to the same value though they are never quite identical. With continued exercise, or under a variety of other conditions, they diverge more and more. The threshold of discrimination—what the operator *can* do—is little affected, except in extreme cases; the threshold of indifference—what is treated as *worth* doing—may rise to double, treble, or

quadruple its original value. Moreover, however this standard of work is set it may be, though it is not necessarily, entirely a neurological affair. The operator may know nothing about it. He may assert that his skill is exactly as it was, and if he is stopped and his threshold of discrimination measured he may appear to be right. For a genuine measure of his skill he needs to have both these thresholds determined within the operation itself.

Results of These Experimental Studies

Let me now try to sum up the main results of these developing experimental studies of skill so far as the linkage of receptor and effector functions is concerned. By far the most important one is that no measure of isolated function can throw any light upon skill or immediate skill potentiality. The crucial point in the linkage with which we are concerned is the accurate timing of the constituent items within their series. So far as the sensorimotor characteristics of the process go it seems that the important thing is the determination of the overall response times—including the recovery time—in the march from interpretation to action and from action to interpretation. There is a tendency for effector response time to lag and for action to get out of step with signals for action. This can be arrested within limits by increased objective urgency, by volition, and by anticipation, provided it does not run very far ahead. It will be facilitated, unless special precautions are taken, by a rapid fall of immediate recall and by the automatic increase of indifference threshold. Looking at the whole matter from the point of view of classical psychological experiment, the field is now set for a thorough reorientation of the traditional study of reaction times and of the functions of latent after-impulses.

[The second lecture will appear in our next issue.]

A CONCEPTION OF INDUSTRIAL HEALTH*

BY

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At any moment of time, and especially in a relatively free-thinking community, the volume of public support lent to an idea is often as important as the intrinsic novelty of the idea itself, and when the pressure of opinion surpasses a certain critical value action leaps from latency to life. The conception of industrial health now has reached this point. It is, however, always a salutary exercise, on starting a new venture, to consider whether its aims and outlook are really original, whether they represent a step in a process of thought which started long ago, or whether they are merely the return of a cyclical fashion.

Some Preliminary Thoughts

It is also appropriate now to put forward some preliminary thoughts about this new Nuffield Department in King's College, and about the methods of approach which it is intended to adopt in order to study some of the facets of this very wide problem of industrial health. But first, perhaps, the very word "health" itself requires some consideration, as we must remember that the classical conception, which the Greeks called *εὐχ*, had in their day a

limited application, usually to the soundness of the body only, and now, like so many other words of like derivation, it has lost caste and become our English "hygiene" with its stereotyped suggestion of soap and water, teeth and tooth-brushes, forms and files, strictly departmental thinking, and rather dull courses of lectures.

But health surely means, among other things, freedom from disease, good performance at the job, whether of mind or hand, the right rate of growth, and the happiness born of a satisfactory wholeness of existence. Moreover, in their wisdom the founders of this Chair intended to indicate a breadth of interest, especially in the direction of the causation and prevention of disease, which would not have been clearly shown by the use of any other word. It is, then, worth while taking trouble to define what is meant by health, because when a new subject or a new attitude towards an old subject comes into view it is only too easy to be under a misconception about what is meant, or even to say that there is no such thing; and, indeed, the most recent attitude towards medicine, which is often thoughtlessly criticized along these lines, is that of social medicine, which some people deny exists at all, and which others even think is medicine in relation to the State.

It may, therefore, be suggested now that the field of study of our new department here may be considered to be the reciprocal and triple relation between job and health and social state, and it is worth while noting at this point that this contrasts somewhat with a conception based upon industrial *medicine* or *disease* as usually conceived, because there is, of course, no true dividing line between industrial and non-industrial illness.

Foundations of Industrial Health

As long ago as 1670 the Italian doctor Ramazzini laid the foundation stone of industrial health with his book *De Morbis Artificum Diatriba: A Dissertation on the Diseases of Workmen*. Ramazzini was not only a bedside doctor but spent much of his time visiting workshops and mines, noting especially the conditions of work, and his conception of industrial health was wide, as shown by the later editions of his book, which included chapters not only upon the diseases of learned men but even upon the health of nuns—an investigation which we may well imagine to have taxed his ingenuity to a high degree and to have involved secret methods, perhaps including even personal disguise.

After a long interval this work was followed, in the middle of the eighteenth century, by a most brilliant practical demonstration of preventive medicine applied to a small community by the naval captain James Cook, who, on a voyage which lasted more than three years, which stretched from latitude 52° N. to 71° S., and which meant, therefore, going through the Tropics, lost through illness but one out of his crew of 118 men. The Royal Society appropriately marked this feat by awarding him the Copley medal for his paper entitled "The Method taken for Preserving the Health of the Crew of His Majesty's Ship, the *Resolution*, during her late voyage round the world." Now Cook's outstanding demonstration, the more notable because he was a layman, was not so much due to his having made any new discoveries in the science of preventive medicine, but can be ascribed almost entirely to his making the fullest application of the principles which were known at the time, to his attention to detail, and to the fact that he had complete charge of a small and isolated community.

The next step forward in this subject came in 1831 with the publication of a book entitled the *Effects of the Arts*,

* An inaugural lecture delivered at King's College on Feb. 24, 1947.