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Components of Skilled Performance

Human limitations of attention and memory are basic to the analysis of skilled performance.

Michael I. Posner

Since its inception, experimental psychology has been engaged in the task of describing the various component functions man performs in doing skilled tasks. Of particular interest has been the quantitative exploration of the limits of man's performance in each component function. Pioneer investigations concerned how fast a man can begin a response, how much he can see at a single glance, how much time is required for discrimination, and how much of what he sees is retained after a single exposure (*1*). More recently the same questions have been raised in a more general approach to the study of performance limitations in human beings (*2, 3*), which has included investigation not only of individual components but also of the interactions between components. This approach was called human performance theory by the late Paul Fitts, who did much to develop it in this country.

Under the influence of developments in communications engineering and computer science, recent studies in experimental psychology have employed much of the logic and language and some of the mathematics of information and communication theory. These influences are apparent in studies concerning the maximum rate of information transmission in human beings, limitation in the capacity for discriminating sensory information, the capacity of visual and auditory short-term memory stores, and the trade-off between speed and accuracy of responses (*2, 4*); all these studies incorporate the older interest in the limitations of man's capacities within the newer analytic framework. Occasionally the number and complexity of component functions, particularly in studies of intellectual performance, are so great that the psychologist turns to computer simulation as a technique for exploring the interaction of these functions (*5*). More typically, and with much the same goal, investigators have used traditional laboratory methods to measure the components of skill and to understand their interactions.

This article is concerned with the limitations of attention and memory in the performance of skills. Prior to the birth of experimental psychology, philosophers discussed limitations in the span of attention (the number of items to which a man could attend simultaneously) and in the memory span (the number of items a man could report after a single presentation) (*6*). The experimental analysis of these limitations was among the earliest undertaken by psychologists. This article begins with recent efforts to determine a channel capacity for man in simple tasks of information transmission. Although no general limitation to man's rate of processing information has been found, results of such experiments lead to techniques by which the amount of attention required can be controlled by varying the processing demands of the task. In the second section, I discuss use of these techniques to demonstrate that the rate of loss of information from a short-term memory system depends upon the processing capacity (attention) available during a brief period after presentation of the stimulus. In later sections I build upon this analysis to discuss the phenomena of interference and imagery within this general framework. In the final section reference is made to some applications of these principles in the study of familiar skills.

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Information Processing Rates

The rate at which man can perform repetitive responses is limited. Such diverse movements as tapping the finger, moving the eyes, or saying short words can be made no more often than about ten times per second (*1*). Moreover, the limitation appears to be of the central nervous system rather than of the muscles themselves (*7*). It had been known since the 1880's that the time required for making a response in a simple key-pressing task increases logarithmically as the number of alternative stimulus-response combinations is varied from one through ten (*8*). With the advent of information measures (*9*), it was quickly shown that in many situations reaction time is a linear function of the information transmitted (*10*). Some investigators hoped to find a maximum rate (channel capacity) at which man can transmit information, which would permit quantitative analysis of human attention.

Figure 1 shows the results of a number of reaction-time studies conducted with a view to attaining this goal. In these studies the number of possible stimulus-response combinations is varied and the subject responds as quickly as possible to the particular stimulus presented on a given trial by making the response appropriate to that stimulus. The linear relation between information and time is apparent in every curve, but the slopes vary markedly with different stimulus and response codes. Lines *A*, *B*, and *C* of Fig. 1 represent tasks which require transformation from a symbolic to a spatial code—for example, from an arabic number to pressing a key, or from a spatial array of lights to a spoken digit. These codes, which had been used in the earliest studies, give steep slopes and are called incompatible. Lines *D*, *E*, and *F* represent spatial stimulus and response codes, but in different planes. The stimulus lights are presented in the vertical plane, while the keys are in the horizontal plane. The absolute speed is greater than for *A*, *B*, and *C* and the slopes are somewhat reduced. Lines *G*, *H*, and *J* represent either symbolic stimulus and response or spatial stimulus and response codes within the same plane. For example, curve *J* represents a situation in which the subject's hands rest upon vibrators. Curve *I* represents the data for one subject who had to press keys in response to lights, but who had been given 6 month's practice at the task.

These data indicate that the rate of information processing in human beings varies sharply with practice and with different stimulus and response codes. Moreover, tasks such as naming words and pressing vibrating keys (*11*) show no increase in reaction time with increasing amounts of information, while other tasks which show an increase as information varies from 1 to 3 bits do not show an increase above this value (*12*). For these reasons, the concept of a finite maximum capacity for information transmission in tasks of this type is not acceptable. These findings do not mean that such a capacity cannot be found under more restricted conditions, such as for tasks in which a particular alphabet is used, or for movements of a particular type. In fact, Quastler and Wulff (*13*) have shown that such capacities can be found for tasks like typing and playing music, while Fitts (*14*) has demonstrated the usefulness of this concept for tasks which involve linear movements of varying required accuracy.

Transformations

The speed with which man can respond to a stimulus reflects the difficulty of the processing which relates input and output information. What are the ways in which stimulus input can be converted to response output? In detail, there are as many ways as there are different tasks which man performs. However, in terms of the informational requirements of the tasks, three logical categories can be distinguished. The tasks shown in Fig. 1 require the subject to conserve information from input to output. Regardless of whether the task involves an energy or a spatial transformation, if it is to be performed without error the input information must be preserved. It is clear, however, that man is more than just an information-transmitting channel. He can act as a source of new information not present in a given stimulus, or he can decrease information, not merely through the making of errors but also through a recoding which is a reflection of the stimulus information in a condensed output (*15*). Here I am not concerned with tasks in which man is required to elaborate upon the input information. I consider tasks, such as addition and classification, which involve information reduction.

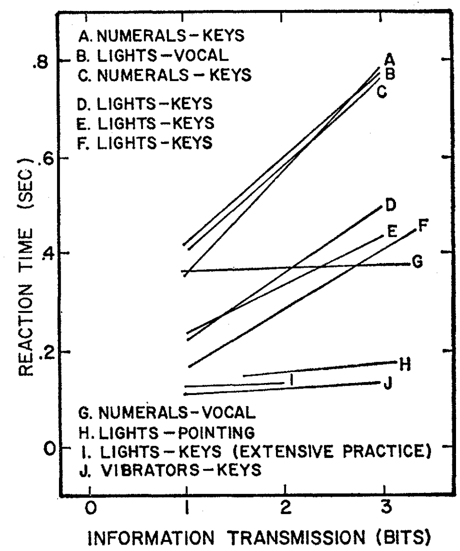


Fig. 1. Reaction time as a function of information transmitted for tasks of varying levels of stimulus-response compatibility. [For a list of the studies from which the figure is constructed, see *33*]

How can the difficulty of transforming input to output be analyzed for information-conserving tasks? With the amount of transmission held constant, the degree of compatibility between stimulus and response codes is the variable used to compare the difficulty of transformation processes. Several methods of measuring compatability have been suggested (*16*). One involves ratings or preferential choices (population stereotypes) collected from a sample of subjects, which indicate what response is most natural for a particular stimulus code. Another method is that of comparing the absolute level, or, more usually, the slopes of curves like those of Fig. 1. Estimates of stimulus-response compatibility are usually obtained from a population of relatively unpracticed subjects (*17*). However, initial differences between tasks in their degree of stimulus-response compatibility continue to affect performance after many weeks of training (*16*). It is possible, therefore, to use relative stimulus-response compatibility as a means of comparing the difficulty of the processing or transformation involved in different tasks. If stimulus-response compatibility is defined in terms of the rate at which information can be transmitted, it may then be used to predict other aspects of information processing, like the ability of subjects to perform two tasks simultaneously.

For information-reduction tasks, a

more direct analysis of transformation size is possible, although it is not known how general this will prove to be in predicting the relative difficulty of tasks. For reduction tasks the input information minus the output information provides a direct and objective measure of the size of the transformation. In order to make such a measure reasonable, it is necessary to restrict consideration to tasks which do not allow selection from among stimulus elements, but which require the individual to process all the input in making his response. For example, in adding, the sum represents less information than the components represent, but each digit must be processed in computing the sum. Tasks of this type are said to involve condensation.

Several years ago I tested the hypothesis that the amount of information reduction is related to the difficulty of the transformation for a restricted set of tasks (*15*). The tasks all involved the same 48-bit input, consisting of eight numbers. Groups of subjects were required either to record the stimuli or to operate upon them by means of a number of information-reducing tasks. The tasks chosen were such that the output information varied from 48 down to 7.7 bits, no aspect of the input could be ignored in producing a correct response, and the component operations involved were relatively familiar. The tasks included a recording task; alternate recording and summing of the digits of a given number; a partial addition task in which successive pairs of numbers were added together; a 2-bit classification task in which the numbers were classified into four categories—high-odd, low-odd, and so on; and a 1-bit classification task where high and odd or low and even formed one category and high and even or low and odd, the other.

Since these tasks could not be compared directly because the errors were so different, each task was performed at speeds varying from input of one number every four seconds to input of one number per second. The rate of decline in performance with increased speed was calculated for each task. When this rate was plotted against the amount of information reduction required by the task, the relations were found to be linear. That is, as the amount of required information reduction increased, the effectiveness of speed in reducing performance also increased in a regular fashion. For this set of tasks the size of the transformation, as measured by the amount of information reduction, is related to the difficulty, or the amount of processing the task requires. Just as in the case of information-conserving tasks, the relationship between information reduction and difficulty is attenuated as practice on the tasks continues, but the differences do not seem to disappear, at least not with modest levels of practice. For this set of tasks, then, a quantitative analysis of transformation size has been obtained and shown to be closely related to task difficulty.

When man performs an easy task he is able to attend to other aspects of the environment at the same time. Walking, for example, causes little or no interference with speech. As the difficulty of a task increases, it demands more of man's limited attention, and the spare capacity available for dealing with other signals is reduced. Such a limited processing capacity is not identical to a channel capacity in the information-theory sense, since it depends upon the type of transformation process involved. Moreover, this limitation cannot be viewed as static; rather, it changes with the level of practice. For example, when one is learning to ice-skate, it may be difficult to converse at the same time. When one becomes proficient at skating, normal conversation can return. However, a task which is difficult initially will generally continue to demand more attention, even after many weeks of practice, than one which is not.

These anecdotal observations are confirmed by experiment. The amount of practice on a reaction-time task has been shown to affect the degree of interference observed when the subject attempts to do mental arithmetic while performing the reaction-time task. Practice is effective, however, only when the signals in the reaction-time task are regular, so that the subject can learn to anticipate them (*18*). It has also been shown (*19*) that when the stimulus-response codes were highly compatible, the reaction-time task caused little interference with mental arithmetic. The compatible primary task was pressing the finger upon a vibrating key. However, an incompatible primary task of pressing the key under the corresponding finger of the hand opposite the vibrator caused much more interference with the performance of mental arithmetic.

Transformation Size and Retention

In the preceding section it was stated that the ability to perform a second task simultaneously with the primary task depends, in part, upon the stimulus-response compatibility of the primary task. Thus, the level of stimulus-response compatibility can be used to control the spare processing capacity which the subject has available for dealing with new information. Similarly, the amount of required information reduction in the numerical tasks described above may be related to the capacity available for processing new information. This hypothesis could be tested directly by requiring the subject to process new incoming information while performing tasks requiring varying degrees of information reduction. No tests of this type have been made, to my knowledge, but an important consequence of the hypothesis has been tested.

Most skilled tasks involve a combination of transformation of new input and retention of previously presented information. Reading a book, listening to a lecture, or driving an automobile are examples. In these tasks, what is the relation between memory of previous input and attention to incoming stimuli?

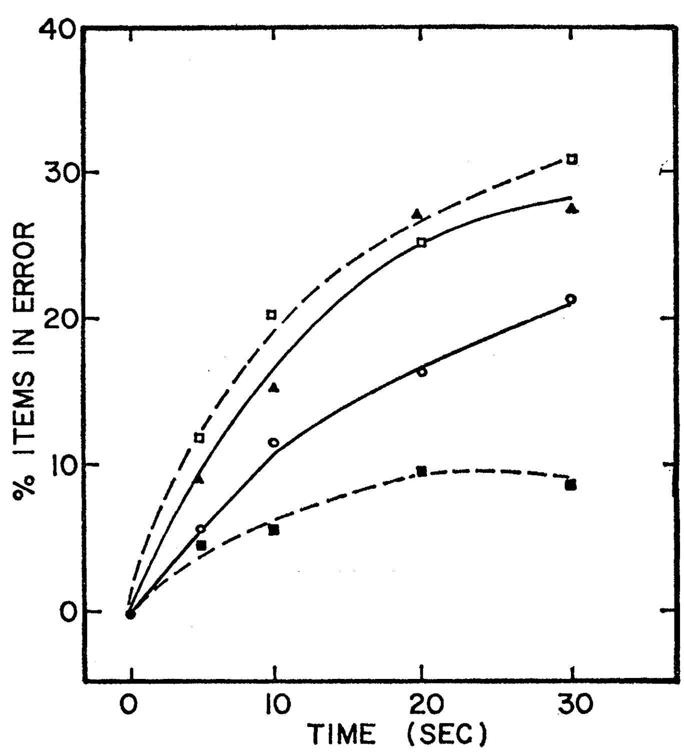
Studies of short-term memory suggest the nature of this relation. In 1959 Peterson and Peterson (*20*) asked subjects to remember three letters while counting backward from a three-digit number for a variable time. They found a dramatic loss in correct recalls as the time increased from 3 to 18 seconds. This result, along with many other studies, shows that forgetting can be rapid when the subject's attention is controlled. If the notion of a processing capacity is accepted, then the degree of available capacity ought to be related to the rate of forgetting.

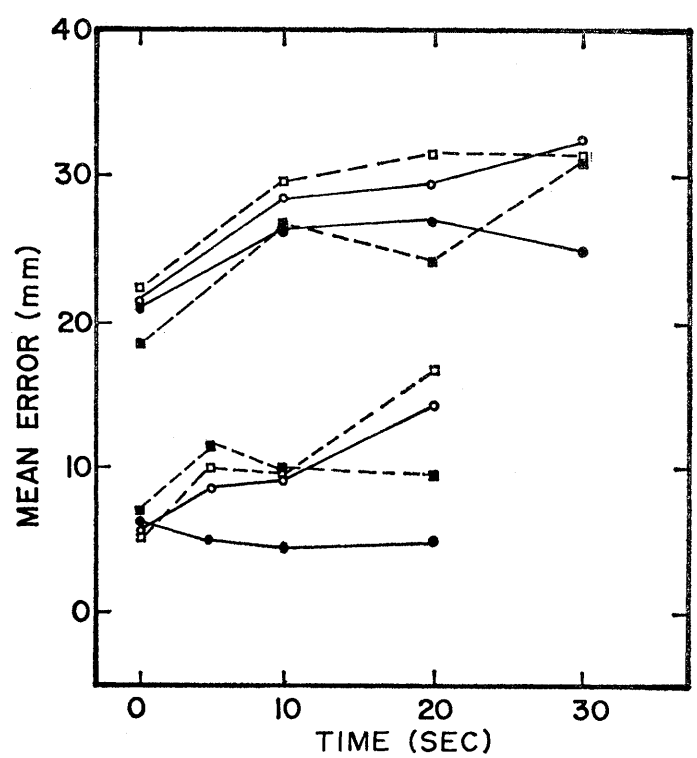
In a series of studies we found clear confirmation of this prediction (*21*). In the first study, subjects were presented with eight randomly selected digits at a rate of one digit every 2 seconds. There were four groups of subjects, each group assigned a given type of information-reducing task with successive pairs of digits. The tasks involved recording, addition, and classification and were similar to those described above. Within each group, subjects were required to transform, in separate series, either the last pair of digits, the last two pairs, or the last three pairs. After the eight digits were presented, the subjects attempted to recall them, in order, without reference to the transformation. Only the first pair of digits, which was never itself transformed, was scored. The results showed a linear increase in error as the number of required transformations of digit pairs increased; the rate of this increase in error was a regular function of the size of the transformation (in terms of information reduced) required by the task. For example, the average increase in recall errors per transformation was five times as great for the classification task as for the simple recording task.

These effects are not due to the increased time in store which occurs with a difficult transformation. In another study, subjects were required to perform transformations of various sizes, for a fixed period (10 seconds), following presentation of three digits which were to be remembered. The digits to be recalled were presented orally, while the digit pairs to be transformed were on paper in front of the subject. This allowed the subject to proceed at his own pace in transforming the digit pairs. Thus, many more digit pairs were interpolated when the task was easy (recording) than when it was difficult (classification). However, results showed four times as many recall errors for the classification task as for the recording task. The results from a related study are shown in Fig. 2. In this study the joint effect of time in store and difficulty of the interpolated task was explored. The interpolated tasks were recording (O bit reduction in input), addition (2.8 bits reduction), and classification (4.6 bits reduction). For comparison, effects of a counting-backward task, frequently used in memory work, were also studied. Figure 2 shows clearly that the difficulty of the transformation is regularly related to the amount of forgetting.

Crowder (*22*) has shown that the same relationship between attention and memory holds when the compatibility of an interpolated information-conserving task is varied. The items to be retained were familiar English words, while the interpolated task involved key pressing, of varying levels of compatibility, which was paced by the experimenter or by the subject. Tasks of low stimulus-response compatibility caused significantly more forgetting than those of high compatibility.

These results are not very surprising. We all know that having our attention distracted after we have looked up a phone number may cause us to forget the number. The important point here is that the degree of distraction, or of attention given the intervening task, can be manipulated, and that this degree of distraction is systematically related to the amount of forgetting. If man is considered to have limited capacity for processing information, these studies indicate that whatever sustains the memory trace during the first few seconds after presentation requires a portion of that capacity. This process has often been called rehearsal. Rehearsal, as the term is used here, is not identical with covert speech and may vary in strength depending upon the processing capacity available to it. It is perfectly reasonable to talk about rehearsal of nonverbal as well as verbal material. Whether all forms of retention require central processing capacity, and hence rehearsal, can only be determined empirically. Presumably, traces differ in the amount of rehearsal required before the establishment of a memory which does not depend upon continued availability of





Figs. 2 and 3. Fig. 2 (left). Percentage of recall errors as a function of retention intervals filled with different information-reducing transformations (*21*). (Solid squares) Recording; (circles) addition; (triangles) backward counting; (open squares) classification. Fig. 3 (right). Mean error in the accuracy of reproducing the original stimulus as a function of delay interval and difficulty of interpolated activity. The top set of curves represents a kinesthetic task; the bottom set, a visual task (see text). (Solid circles) Resting; (solid squares) recording; (open circles) addition; (open squares) classification.

processing capacity. While these conclusions are based upon studies of human subjects, they are in qualitative accord with results obtained in animal studies of "consolidation processes" in memory.

Role of Interference

Is loss of information from short-term store an inevitable consequence when rehearsal is controlled? The answer from both everyday experience and experiment is clearly no. Some items are retained despite deep and prolonged distraction. For example, in none of the conditions of Fig. 2 were more than half the items lost. Of course, the amount of forgetting depends upon a variety of things besides rehearsal. In one study (*23*) it was shown that, on the very first trial of a memory experiment like those discussed above, there is little or no loss in retention over 18 seconds of counting backward. It is not until the subjects have had two or three trials that prevention of rehearsal causes a rapid fall-off in performance. Moreover, it has been shown that if a subject is switched to a new type of material after a number of trials, on the first trial after the switch the probability of error is greatly reduced (*24*). These studies indicate the importance of the number of stored items and the similarity of the stored items to each other in determining the level of retention.

In order to understand the interaction of attention and memory in skilled tasks, one must know when a given level of rehearsal prevention is likely to result in forgetting. The experiments discussed below were conducted in an effort to describe how the number of stored items and their similarity to a new item affects the rate of forgetting the new item. Two different views are possible depending upon whether traces of individual items do or do not remain independent during the retention interval. Perhaps they remain independent and stored material competes with the item to be recalled only at the time of recall. That is, at the moment of recall the subject searches his memory and selects the item that is strongest at that time. According to this "trace comparison" view, traces do not interact during the interval but, because of differential changes in the strength of the traces over time, errors occur due to competition during recall. In contrast, there is the "acid bath" view: competing items do not remain independent, but similar items intermingle during the retention interval and destroy the information contained in the trace. The simplest "acid bath" model would be one in which the effectiveness of competing items (interference) depends only upon time and the similarity between the stored traces. [The analogy with an acid bath is this: if an object sat in an infinite acid bath, the absolute magnitude of the effects of the acid (interference) would not be reduced by an operation (rehearsal) which added to the size of the object.] On the other hand, any "trace comparison" view predicts that, as rehearsal is reduced, competition among traces at recall must increase. Thus these views lead to quite different predictions about the result of controlling attention during the retention interval; while both models suggest that rehearsal will improve retention, the trace comparison view suggests that it will also diminish interference effects, while the acid bath view does not.

In a series of experiments we systematically manipulated the similarity among stored items by using populations of letters of either high or low acoustic similarity (*25*). Acoustic similarity has been shown by others to exert important influence upon recall scores (*26*). In connection with each letter population we used two interpolated tasks requiring different degrees of information reduction, addition and classification, which had been shown to control rehearsal differentially. Groups of subjects were tested with one of the letter populations but with both types of interpolated tasks and with delay intervals of 0, 5, 10, and 20 seconds.

All the main effects of similarity of items and difficulty of interpolated task were significant and in the expected direction. Both high similarity of items and high difficulty of task increased forgetting. What is crucial is the effectiveness of interference, as measured by the difference in recall errors between items of low and of high similarity at the two levels of interpolated-task difficulty. These effects are shown in Table 1 in terms of percentages of letters incorrectly recalled, averaged across two independent experiments, for each time interval.

The results, which are confirmed by statistical analysis and which hold up in both studies, are quite simple. The effectiveness of interference was never greater under the high-difficulty task than under the low-difficulty task, as the trace-comparison view would require. Moreover, the values for the two tasks are closely related to the interval of time the items have been in store, though the interference effects remain roughly constant after the first 5 seconds. These data provide some support for a view of the "acid bath" type.

The "acid bath" view is closely related both to the decay theory and the interference theory of short-term memory. Moreover, related models have been suggested by a number of recent findings (*27*). The "acid bath" view implies the following concerning the behavior of items stored in short-term memory. Stored items tend to lose precision of information over time. Such effects may be eliminated when full processing capacity is available for rehearsal. However, when opportunity for rehearsal is reduced, the rate at which precision is lost is a function of the number and similarity of items which have been stored in short-term memory. Thus, the rate of decay is a function of the amount of interference among items. Interference itself is a function both of the amount of "acid" (the number of stored items) and its "concentration" (the similarity of the stored items). That the number of items is important in determining the rate of forgetting is clear from the limitation of the memory span. As the number of items which are stored increases, the effectiveness of a period of free rehearsal in preventing loss during a subsequent task is reduced. Our study (*25*) shows remarkably similar effects of item similarity when it is manipulated by acoustic pattern. When items are similar the rate of loss of information for a fixed number of items is increased and the effectiveness of rehearsal tends to be reduced.

Since many language skills demand the continuous intake, storage, and recall of information, such skills pro-

Table 1. Effectiveness of interference as a function of difficulty of the interpolated task (addition or classification) for all time intervals. (Effectiveness of interference is given in terms of the difference in percentage of recall errors for low acoustic confusion and high acoustic confusion.)

Time interval (sec.)	Effectiveness of interference	
	Addition	Classification
0	3.6	4.9
5	14.7	14.5
10	12.6	11.8
20	20	15

vide nearly optimum conditions for the occurrence of forgetting. The intake of new items tends to block rehearsal, while the competition from earlier items leads to a rapid loss in precision. Because of the rapid loss of stored information in such situations, memory limitations are basic to the information processing analysis of many skills.

Imagery

One of the limitations of the evidence presented so far is that only retention of materials such as letters, digits, and words which are easily stored in verbal form has been discussed. Many skills involve the retention of patterns of visual or kinesthetic information which may not be easily or completely encoded in words. The typed letters *A* and *a* are usually given an indentical verbal coding, but it is possible that retention of their visual difference may still remain. Several recent studies (*28*) of perceptual-motor skills have suggested that nonverbal information concerning the distance, form, and location of prior movements must be stored between successive trials. This type of storage of nonverbal material is usually called imagery. Evidence (*29*) has indicated that such information is lost over time, but relatively little is known about the details of short-term retention of these materials.

Studies currently in progress in our laboratory are directed toward the incorporation of imagery within a general information-processing framework. Two different tasks are being studied. At present we know that these two memory situations give strikingly different results, but we are not completely sure why this is so.

In the first task the subject must recall the location of a point at one of 12 positions along a 180-millimeter line. He is given about 1 second in which to view the position of a circle on the line, and after a variable delay he must indicate the location of the circle's center on an identical unmarked line. Since similar results are obtained whether or not the subject moves his hand to the original target, it is clear that in this task the subject must rely upon visual information.

In the second task the subject moves a lever one of 12 distances from a starting position to a finish peg. He must then reproduce this distance in a second box in which the lever starts at a new position. Since he cannot see his hand in either box, his only source of information is kinesthetic.

In each task, two major independent variables are considered. First, the length of time between exposure and recall is varied, in the range from 0 to 30 seconds. Second, the difficulty of the interpolated information transformations is varied. The results shown in Fig. 3 are typical for the two tasks. In these experiments there were four groups of 12 subjects each. Each subject was assigned one interpolated task. During the experiment each subject reproduced the 12 distances four times, each time with a different delay interval.

The top set of curves in Fig. 3 represents the second or kinesthetic task. The basic pattern, which is shown in Fig. 3 and which is confirmed by statistical analysis and by subsequent replication, indicates that the mean error or reproduction increases regularly with delay. This is true even when the subject has no task to perform during the interval. Moreover, there are no significant differences in the curves for various interpolated tasks: forgetting is not significantly more rapid under the classification condition than under the resting condition. Both the loss of accuracy over time in the resting condition and the lack of differences in the curves for various interpolated tasks distinguish these results from those of the verbal tasks studied previously. Retention seems not to depend upon the central processing capacity available during the retention interval.

The results for the first, or visual task, are quite different. In this task, with the resting condition there is no forgetting at all. Moreover, the curve for the recording condition, in which the subject must deal with as many digits as he deals with under the other conditions, shows little evidence of forgetting over time. In two separate studies, comparison of the results for the 0-second and 20-second intervals for the recording condition indicates that half the subjects show increasing error over the interval and half show decreasing error. However, under the classification condition, every subject shows an increase in error. Moreover, the interpolated tasks order themselves in the same way, from the standpoint of difficulty, as in the previous verbal studies. For this task, forgetting is clearly a function of the processing capacity available during the interval.

The most obvious explanation of the difference in results for the two tasks is the explanation that subjects are using numbers for retaining information in the visual but not in the kinesthetic task. A detailed analysis of the date argues against this explanation. The introspective reports of the subjects obtained after the experiment indicate in all conditions the use of crude verbal labels, such as left or right of center, and so on. However, this use of imprecise verbal labels cannot account for the extreme accuracy found, particularly in the visual task. Even if the subjects were assigning numbers accurately to the nearest inch, they could not, by this means, achieve the accuracy of reproduction that is obtained. Only one or two subjects reported use of labels as precise as this, and they showed no evidence of superior performance. Moreover, there was no indication of the large errors which would be expected if subjects were forgetting verbal labels. Analysis of the median errors, in which the effects of a few large errors would tend to be eliminated, indicates the same results as shown in Fig. 3 for means. Some verbalization undoubtedly is involved, but it seems to be equally extensive in the two situations—visual and kinesthetic—and not sufficient to account for the observed accuracy of reproduction.

If the differences in results for the two tasks do not lie in the degree of verbalization, why does the retention of information in the visual task seem to depend upon available processing capacity while in the kinesthetic task it does not? At present our work is directed toward finding the answer to this question. It may lie in fundamental characteristics of the two modalities, or it may lie in other differences between the two tasks, such as the requirement for retaining a location fixed in space as compared with the requirement for retaining a distance which must be integrated over time.

The results obtained thus far indicate support for the view that some memory tasks involve retention of information in nonverbal form and that such information is subject to forgetting which can be measured over time. The results also indicate that these tasks may differ from each other and from verbal tasks in the extent to which they are affected by control of the subject's central processing capacity. These effects are not due to differences in the initial level of accuracy of retention. In fact our present work indicates that, when measured in similar situations, the initial accuracy of retention for the two modalities is rather similar, but the crucial differences discussed above remain. Since it is possible to measure the amount of information generated by the reproduced responses after each delay interval, it is possible to make direct comparisons of the informational capacity and decay characteristics of various memory systems.

Applications

Human performance theory has for its goal the analysis of skills. The capacities of attention and memory which are explored in this article play an important role in many types of performance. In order to illustrate this viewpoint, in the space remaining I review a few examples of the application of techniques developed in the experimental laboratory to the analysis of familiar tasks.

Shepard and Sheenan (*30*) have shown the usefulness of data on man's limited memory span to the design of optimum systems for the storage and retrieval of numbers of the type used in telephone dialing. In a proposed system they seek to minimize storage time for the high-information portions of the number by allowing the familiar prefix code to be dailed last. This simple procedure cut errors by 50 percent.

Another common task which has been studied involves the measurement of performance during automobile driving as a function of road, traffic, and vehicle conditions. Normally it is difficult to make such comparisons because the details of the skill shift with the independent variable. Brown and Poulton (*31*) approach this problem by adding a simple numerical task to the primary skill and observing changes in the capacity available for processing the numerical information. The amount of spare capacity shows predictable changes as the driving task demands more of the subject's attention.

At a more complex level, recent efforts have been made to analyze the processes of induction in terms of informational transformations and memory. In several studies it has been found that the amount of information to be absorbed on a given trial affects the ability of subjects to make full use of incoming evidence. Studies of this type have led to proposals for systems of decision-making in which machines are used to relieve man of memory load and other limitations which affect his ability to combine information over time (*32*).

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33. Figure 1 is patterned after a figure in P. M. Fitts, *Human Factors Engineering* (Univ. of Michigan Press, Ann Arbor, 1965). References for the labels are as follows: (*A* and *E*) E. R. F. W. Crossman, in The Applica*tions of Information Theory to Human Operator Problems*, J. Draper, Ed. (Ministry of Supply, London, 1956); (*B, C, G*) R. W. Brainard, T. S. Irby, P. M. Fitts, E. A. Alluisi, *J. Exp. Psychol.* **63**, 105 (1962); (*D*) J. Merkel (see *8*); (*F*) W. E. Hick, *Quart. J. Exp. Psychol.* **4**, 11 (1952); (*H*) P. M. Fitts, J. R. Peterson, G. Wolpe, *J. Exp. Psychol.* **65**, 423 (1963); (*I*) G. H. Mowbray and M. V. Rhoades, *Quart. J. Exp. Psychol.* **12**, 193 (1960); (*J*) J. A. Leonard, *ibid.* **11**, 76 (1959).

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