THE UNIVERSITY OF MICHIGAN

COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS
Department of Psychology

Progress Report

INFORMATION HANDLING AND DECISION MAKING BY INDIVIDUALS AND SMALL TEAMS

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The present program of research was undertaken with the aim of developing general principles and theory that would contribute to the prediction of levels of individual, team, and man—machine system performance as a function of task and system characteristics, such as the kinds of information processing required, the way in which a group is organized, and the kind of input and feedback information displayed to individuals or shared by a team. The successive phases of this program, which were projected to cover approximately five years of work, were to emphasize: (a) methodological problems; (b) systematic empirical studies of performance as a function of task variables; (c) integration of empirical findings and development of theory; and (d) testing of the relevance of generalizations for typical command, control, and information-processing tasks.

Work during the preceding period has been concerned primarily with the second and third phases of this program, with increasing emphasis being placed upon the development of general theory of information-processing behavior. Included in this work has been the research of three doctoral candidates. Two of these theses have been completed and accepted by the Horace Rackham School of Graduate Studies of The University of Michigan. Dr. Heber Moore's thesis has been distributed as an OSR Report; Dr. Posner's thesis is awaiting distribution. The other, by Mr. Theron Stimmel, is still in progress.

Other investigators who have attempted to apply concepts from information theory to the study of human performance have tended to emphasize relatively simple information-transmission tasks and stimulus variables, such as discriminability and level of uncertainty. The present research program has turned increasingly to the investigation of cognitive processes in information handling, including the study of tasks which require information translation, information reduction, and the choice of one or a small number of alternatives from a very large set of possible alternatives. Parallel theoretical work has placed increasing emphasis on set and expectancy, and on thinking and decision processes. Investigations have also included studies of the ability of subjects to devise and use heuristic methods in information-reduction tasks. All of this work is viewed as contributing to a general theory of human information processing.

The previous progress report outlined a taxonomy which included five levels of information processing. These were: (1) complete (100%) information transmission; (2) partial information transmission (filtering); (3) information reduction; (4) application of heuristics in information processing; and (5) decision making. This classification is utilized in the following report in the description of specific experiments.

EFFECTS OF RESPONSE VARIABLES IN COMPLETE INFORMATION-TRANSMISSION TASKS

In this investigation, 100 percent information-transmission capacity was studied as a function of the magnitude and precision required of the response, and also as a function of the uncertainty preceding the stimulus event. The study was an extension and amplification of one published some years ago by the principal investigator (Fitts, P. M., The Information Capacity of the Motor System in Controlling the Amplitude of Movement, J. exp. Psychol., 1954, 47, 381-391). In this earlier study, it was found that the difficulty of a motor task can be specified precisely by the logarithm of the ratio of response precision to response magnitude, i.e., $ID = \log 2A/W_s$, where A is the amplitude of movement and W_s the tolerance limits for terminating the movement. Movement time in a continuous task can be predicted on the assumption that human motor capacity is approximately 10 to 12 bits per second when task difficulty is specified as above.

In the present study, the older data were extended in two ways. First, a discrete reaction situation, rather than a continuous one, was employed. Second, the subject was uncertain as to what movement would be required until the stimulus occurred. The method was as follows. The subject fixated between two lights. The onset of one of these lights indicated which one of two movements should be made. The movement was then executed as quickly as possible, the subject moving a stylus in order to hit a target. Both hits and errors (overshoots and undershoots) were recorded. It was found that the data for reaction time and movement time followed different laws. Reaction time was independent of the precision of the movement to be made, and depended only on the number of alternative movements. Thus reaction time in a standard two-choice situation was slower than reaction time in a control (C reaction) situation where a single movement was required, and the stimulus occurred half the time. In contrast to the reaction-time data, movement-time data were fitted by exactly the same type of function as had been applied in the previous experiment, except that the slope of the function relating movement time to increases in task difficulty was about half as steep as in the previous study (see Fig. 1). In other words, movement time increased linearly as a function

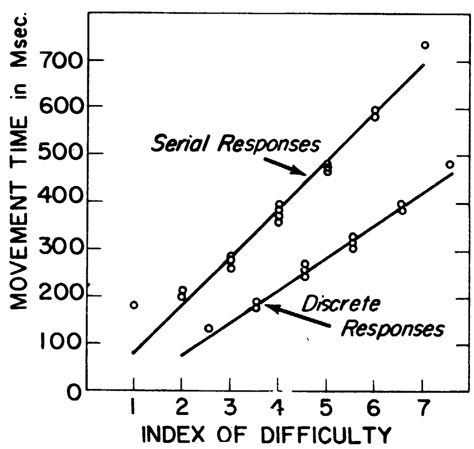


Fig. 1

of the logarithm of the ratio of amplitude to accuracy, except that the rate of increase was less than in the continuous task. This difference in slope is interpreted as indicating an increase in the efficiency of the control of responses in situations in which the individual is allowed a period of time in which to prepare for the response prior to the signal to execute it.

The theoretical importance of this experiment lies in the clear evidence which it provides of a two-stage information-processing activity. That is, the fact that reaction time was unaffected by the nature of the response to be executed, but only by uncertainty regarding the number of alternative responses, whereas the time for the execution of the response was not influenced by uncertainty prior to the stimulus but was determined almost entirely by the precision required by the response itself, is strong evidence in favor of the notion of a sequential choice process followed by a movement execution process. Thus the data are in agreement with one group of recent theories, such as one by Welford, and one by Crossman, which postulate such a sequential process in information handling.

AN INFORMATIONAL APPROACH TO THINKING

The following summary is adapted from the abstract of Dr. Posner's thesis of the same title as above.

The statistical processing of data, the addition of numbers, the formation of concepts, and the reading of a typed page for content are all examples of tasks which require the reduction of information from input to output. Such tasks, in comparison with information-conservation tasks, place emphasis on man's ability to think. The general hypothesis of the present series of studies is that the amount of reduction of information from input to output is an important factor in the amount of thinking required by such tasks. This applies only to tasks which like the ones cited above, require the subject to process the input in such a way that it is all represented in a reduced form in the response, rather than simply to ignore or filter out part of it. This hypothesis leads to the prediction that the greater the amount of information reduction involved in a task, the greater the length of time to complete it, the more errors, the greater the variability from subject to subject, and the longer the learning time. The hypothesis can be applied not only to information-handling tasks, but also to concept formation, problem solving, and the measurement of similarity. Figure 2 gives a general classification of such varied tasks from an informational viewpoint; the top figure illustrates conservation, the middle figure creation, and the bottom figure information reduction.

In the first series of experiments the hypothesis was tested using six simple numerical tasks. Each task involved an identical 48-bit input, but the subject was required to classify or combine the material so as to reduce the re-

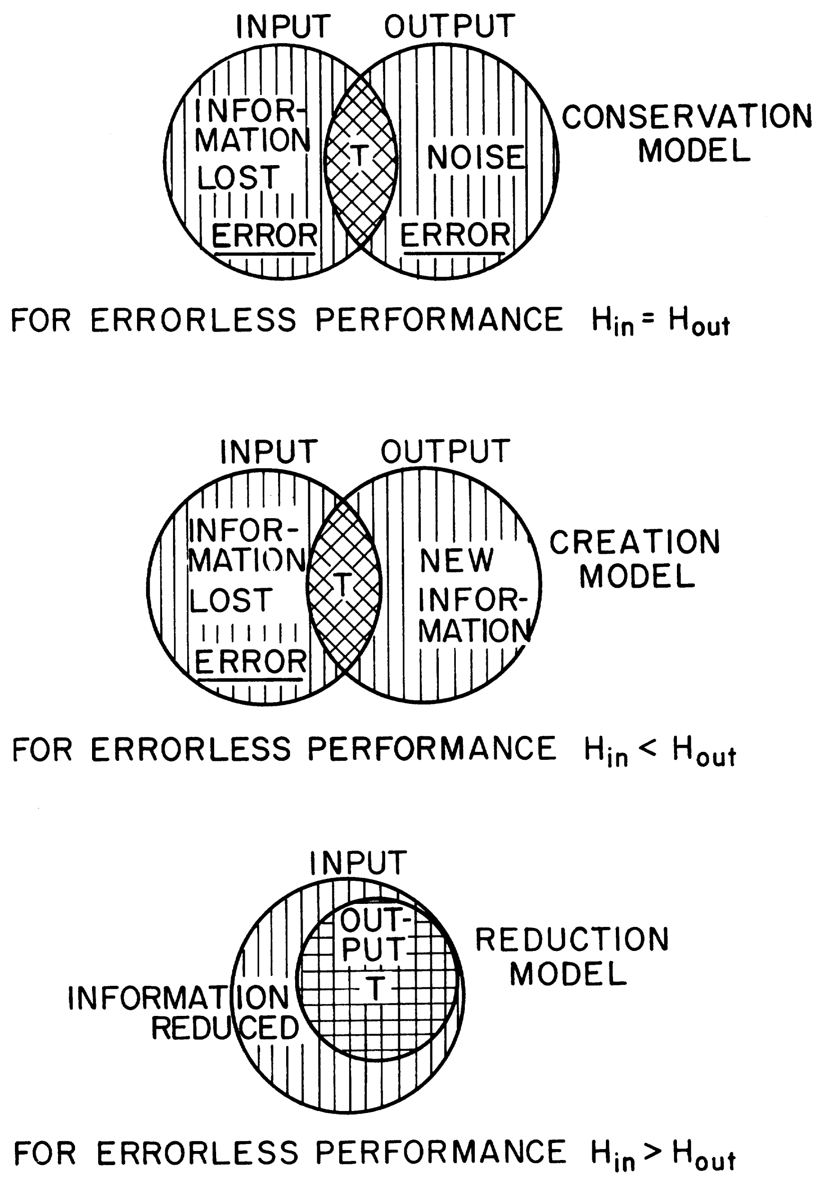

INPUT
OUTPUT
INFORMATION LOST
T
NOISE
ERROR
ERROR
CONSERVATION MODEL
FOR ERRORLESS PERFORMANCE $H_{in} = H_{out}$
INPUT
OUTPUT
INFORMATION LOST
T
NEW INFORMATION
ERROR
CREATION MODEL
FOR ERRORLESS PERFORMANCE $H_{in} < H_{out}$
INPUT
OUTPUT
T
INFORMATION REDUCED
REDUCTION MODEL
FOR ERRORLESS PERFORMANCE $H_{in} > H_{out}$

Fig. 2

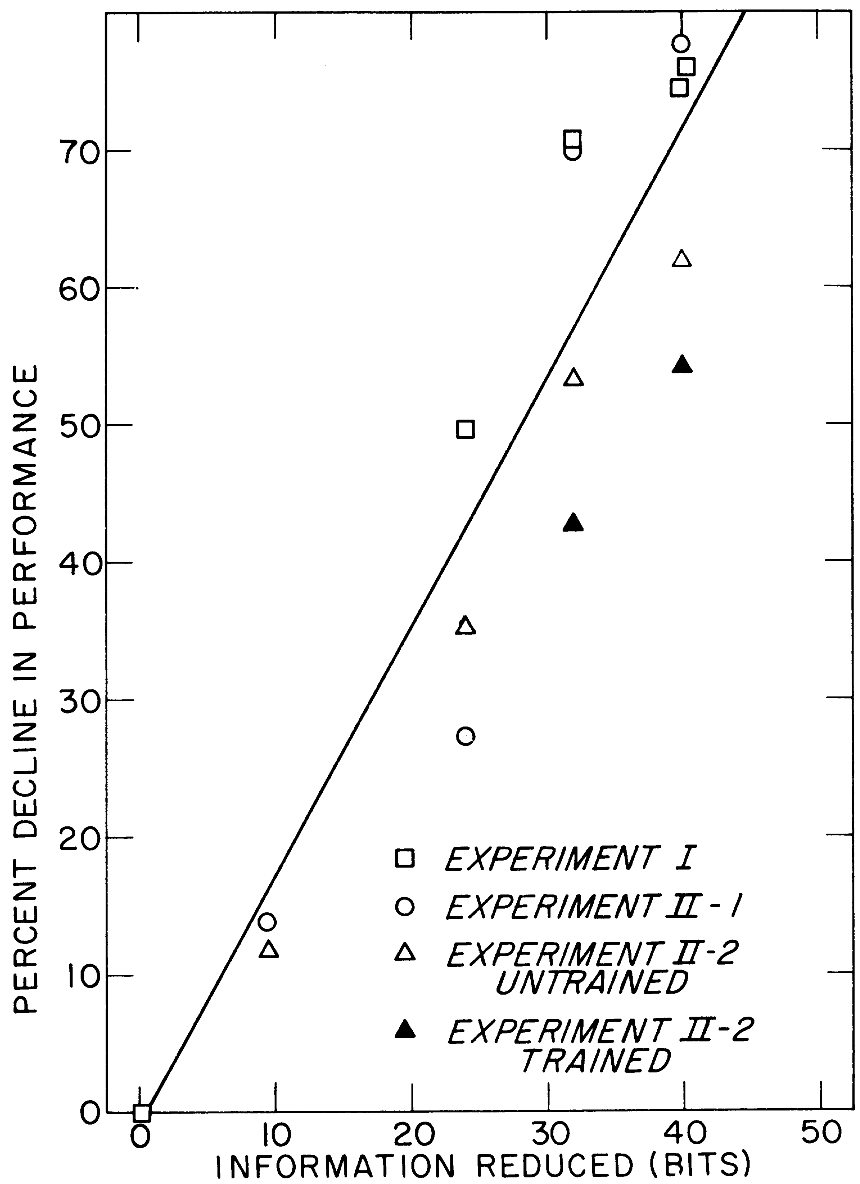

PERCENT DECLINE IN PERFORMANCE
0
10
20
30
40
50
60
70
INFORMATION REDUCED (BITS)
0
10
20
30
40
50
EXPERIMENT I
EXPERIMENT II - I
EXPERIMENT II -2 UNTRAINED
EXPERIMENT II -2 TRAINED

Fig. 3

sponse output by 0, 9,4, 21.5, 32, 40, and 40.3 bits respectively. Uniform linear relationships were found between information reduced on the one hand and objective performance measures and subjective ratings of difficulty on the other hand (see Figs. 3 and 4). The straight line fit improves as the control over sequential dependencies and inter-individual error is increased.

Next, the hypothesis was extended to concept formation and perceptual similarity. Patterns of eight dots were used as stimuli. Each pattern was modified by statistical rules to produce 0, 8, 16, 32, 40, and 48 bit distortions. When used in a standard paired-associate transfer paradigm, a linear relation was found between percentage of transfer and the uncertainty in bits between pairs of patterns (see Fig, 5). This result and that of the same technique applied to discrimination tasks (information conserving) allows the quantification of the stimulus dimensions of the Osgood retroaction and transfer surface (see Fig. 6).

The same materials were used in a reaction-time experiment in which the subjects indicated whether two patterns were linked by the same name. Speed of response was found to be linearly related to uncertainty in the range from 0 to 40 bits (see Fig. 7).

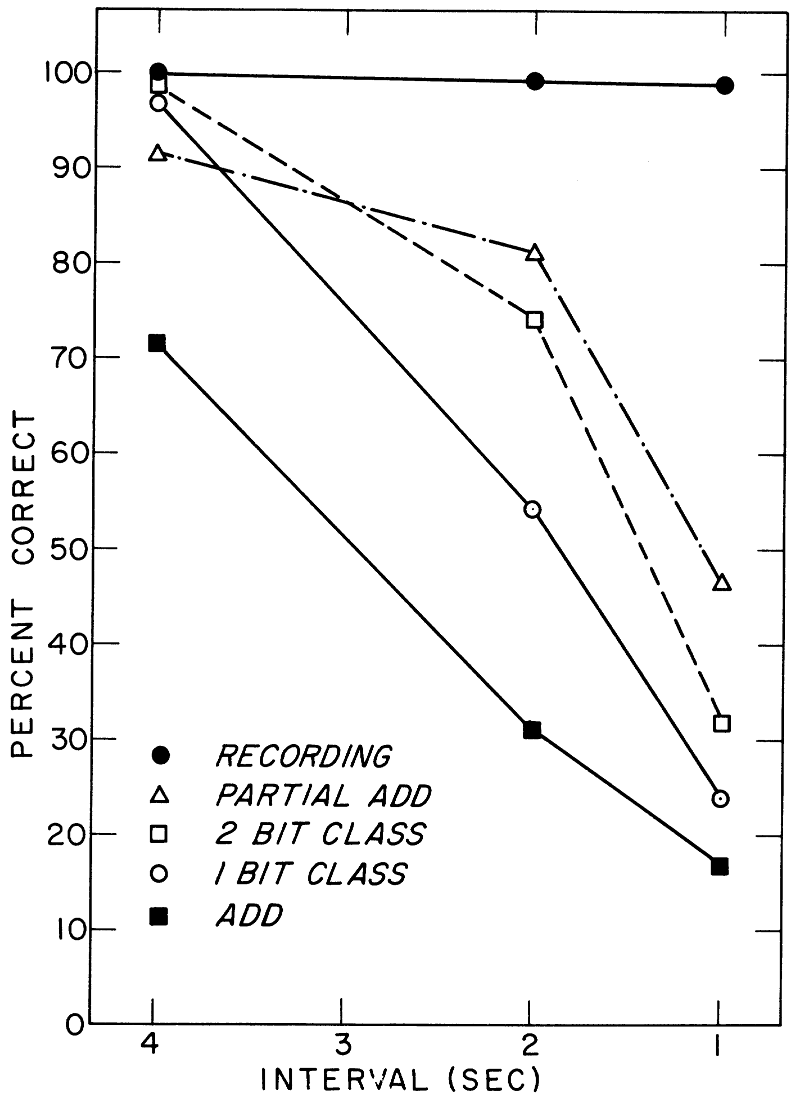
Psychophysical curves were also obtained relating mathematical uncertainty to perceived similarity. Three distortion rules were used to produce mathematical uncertainty. The overall results demonstrated an inverse linear relation consistent over all three rules. However, the slope of the function was steeper for the rule which required all elements of the dot pattern to move than for the two rules which permitted some dots to retain their original locations.

These experiments, taken as a whole, demonstrate the possibility of specifying the amount of thinking required by a psychological task. Within a given task configuration, the information-reduction measure provides accurate prediction of human performance. It provides a base line useful in the comparison of performance among different types of tasks and in the classification of tasks.

HEURISTIC PROCEDURES EMPLOYED IN HUMAN INFORMATION PROCESSING AND DECISION MAKING

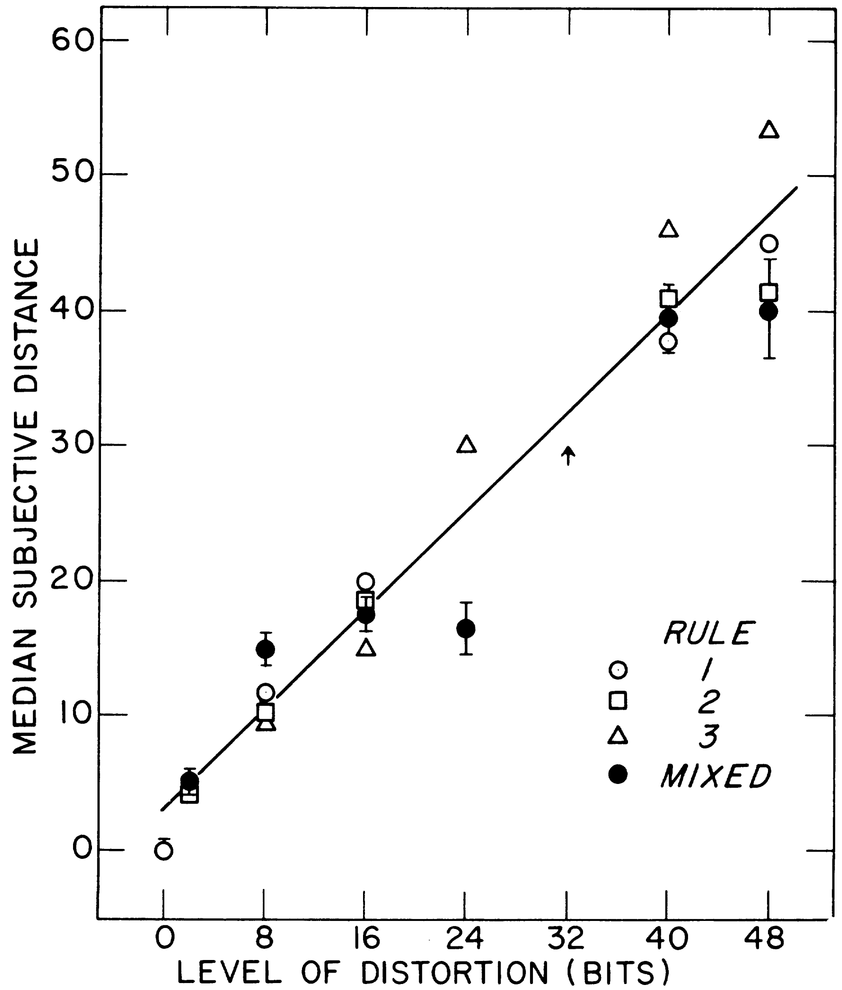
The major work on the use of heuristic procedures in problem solving, completed since the previous progress report, has been carried on by Mr. Theron Stimmel as part of his doctoral dissertation.

Problem solving by people may involve either the use of an algorithmic or heuristic method or both. An algorithmic procedure involves the use of a pre-



100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
4
3
2
1
INTERVAL (SEC)
RECORDING
PARTIAL ADD
2 BIT CLASS
1 BIT CLASS
ADD

Fig. 4



60
50
40
30
20
10
0
MEDIAN SUBJECTIVE DISTANCE
0
8
16
24
32
40
48
LEVEL OF DISTORTION (BITS)
RULE
1
2
3
MIXED

Fig. 5

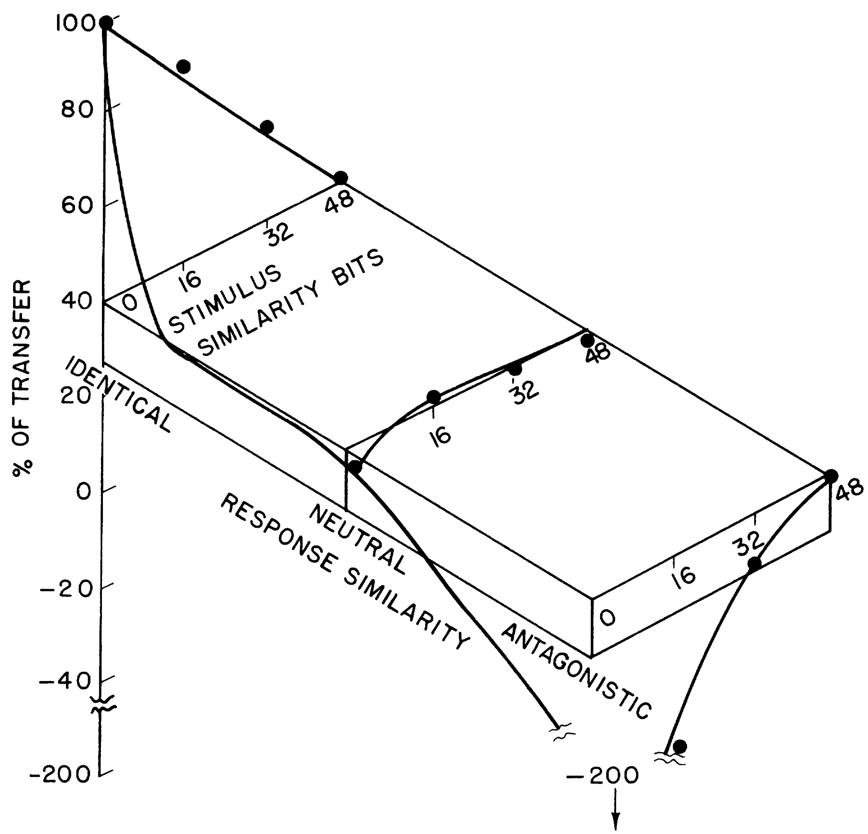

% OF TRANSFER
100
80
60
40
20
0
-20
-40
-200
STIMULUS SIMILARITY BITS
0
16
32
48
IDENTICAL
NEUTRAL
ANTAGONISTIC
RESPONSE SIMILARITY
-200

Fig. 6

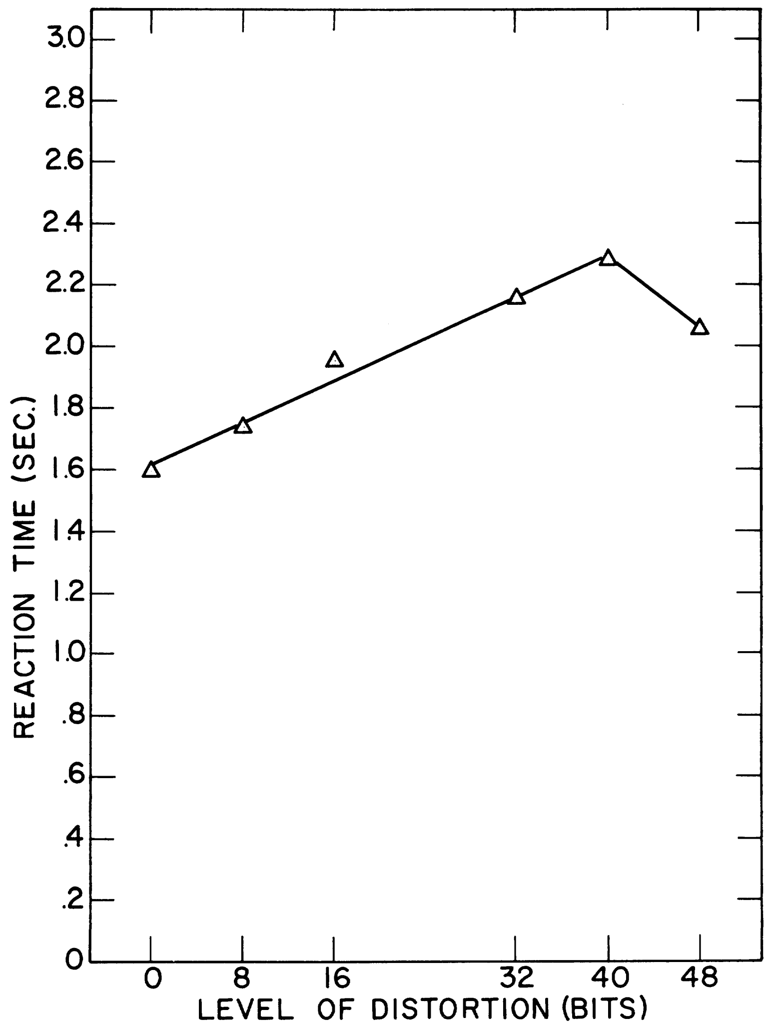

REACTION TIME (SEC.)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
8
16
32
40
48
LEVEL OF DISTORTION (BITS)

Fig. 7

scribed sequence of steps which, if correctly applied, will assure the person of an optimal or perfect solution. A common example of a problem amenable to the use of an algorithmic procedure is the extracting of the square root of a number. The two conditions necessary for the application of an algorithm are: (1) that an algorithm is known, and (2) that it is feasible to apply it in a given situation. If one of these two conditions is not met, then resort is often made to heuristic procedures. As here defined "heuristic" means using the information obtained in one step of a solution to aid in deciding upon the next step; it also means using a problem solving procedure that does not necessarily guarantee an optimal solution.

In the past, experimenters studying human information processing in complex tasks have been primarily concerned with algorithmic procedures. However, a great many of the problems people must solve in everyday life, and many military problems, require the use of heuristic procedures for one of the following three reasons: (1) the person has no algorithm for solving the problem; (2) there is only partial information present; or (3) the cost in time or money makes the use of an algorithm unfeasible. Examples of problems where heuristics are often applied for one or more of these reasons are the scheduling of work by people and/or production machines, the stock market problem, the transportation problem, and the weapons assignment problem.

The transportation problem has been selected for intensive study, chiefly because an algorithm for its solution is known, and hence optimals can be computed but the subject because of limited time must use heuristic methods. In this problem, the person is asked to make transportation assignments from origins to destinations in such a manner as to minimize the total distance covered by all of the assignments.

Previous studies in this series have approached the understanding of the way people deal with the transportation problem from two directions. The first line of approach has studied the physical features in the problem that influence the quality of performance. For example, work has been done on the difference in performance when the information is displayed in a map display vs. the same problem with the information displayed as a matrix (mileage chart). It has been found that people are able to do significantly better using the map display. Another aspect studied has been the effect of the physical dimensions of the problem on the time and accuracy of solutions.

At the present time an experiment is under way to investigate further the effects of varying the smaller dimensions of the problems upon the time to solve and the quality of solution. In a previous study, it was found that in the matrix problem, performance declined as a linear function of the amount of uncertainty reduced by each decision. At present an experiment is under way to determine if this effect holds for both the map display and the matrix display. Subjects in this experiment will receive far more extensive training than subjects in previous experiments. We hope to determine whether previously discovered effects disappear with extensive training, and to study the effects of extensive training on individual differences.

Other current research on the use of heuristics in problem solving is concerned with the effects of past experience and learning variables. Transfer of training effects between displays, the effect of mathematical training, and the effect of extensive training on the strategies people adopt in solving this problem are being studied. The sequences and patterning of decisions are being subjected to an extensive analysis in this work.

INFORMATION PROCESSING AND DECISION MAKING BY TWO-MAN TEAMS

The main body of work in this area has been reported in AFOSR-1636 dated October, 1961. This report is based on Dr. Heber Moore's Ph.D. dissertation. The variables investigated were: (2) free vs. restricted access to information as a function of (b) two levels of input load. The task was a dynamic version of the heuristic problem-solving task discussed in the preceding section. In order to provide realism and heighten motivation, the problem was presented to subjects as one of dispatching taxis to pick up passengers in response to calls received from persons at different locations in a city. Subjects attempted to keep five cabs in continuous operation. Under low load, three passenger calls were received every two minutes, until fifteen passengers had requested service. Under high load, the interval between calls was reduced from two minutes to one minute, and all requests were bunched during the first part of a ten-minute session. Ninety-six male subjects were used, working in forty-eight two-man teams, twelve teams under each of the four conditions. Each team worked for twelve problem sessions, following a preliminary training period.

The general layout of the working environment is shown in Figs. 8 and 9 which illustrate the two conditions of information exchange. Under the restricted communication and information-exchange condition, subjects could not talk directly to each other, but had to communicate by interphone or by passing written messages back and forth. Information about passenger request, cab locations, etc., were in general available to only one of the team members at a time. Results for two of the performance measures employed in the study are shown in Figs. 10 and 11.

The overall criterion which teams attempted to maximize was dollars earned per minute, determined by a formula which took into account the total mileage of the cabs, the number of passengers picked up, the distances passengers were carried, and penalties for excess passenger waiting time. Results shown in Fig. 10 indicate that earnings were highest under conditions of high load plus free access to information. Limited access to information seriously retarded early performance. Figure 11 shows the effects on passenger waiting time of the four experimental variables. In the high-load condition some amount of delay in picking up passengers was inevitable in comparison to the low-load condition; however, the condition of free access to information was superior at both levels of load. Improved performance under the condition of

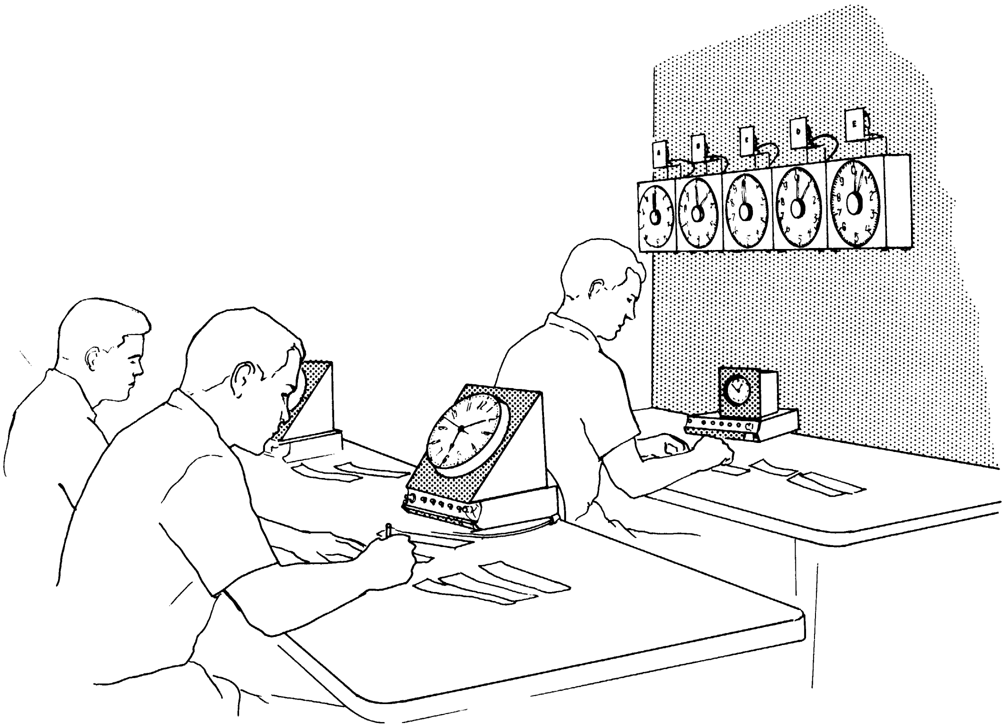


Fig. 8

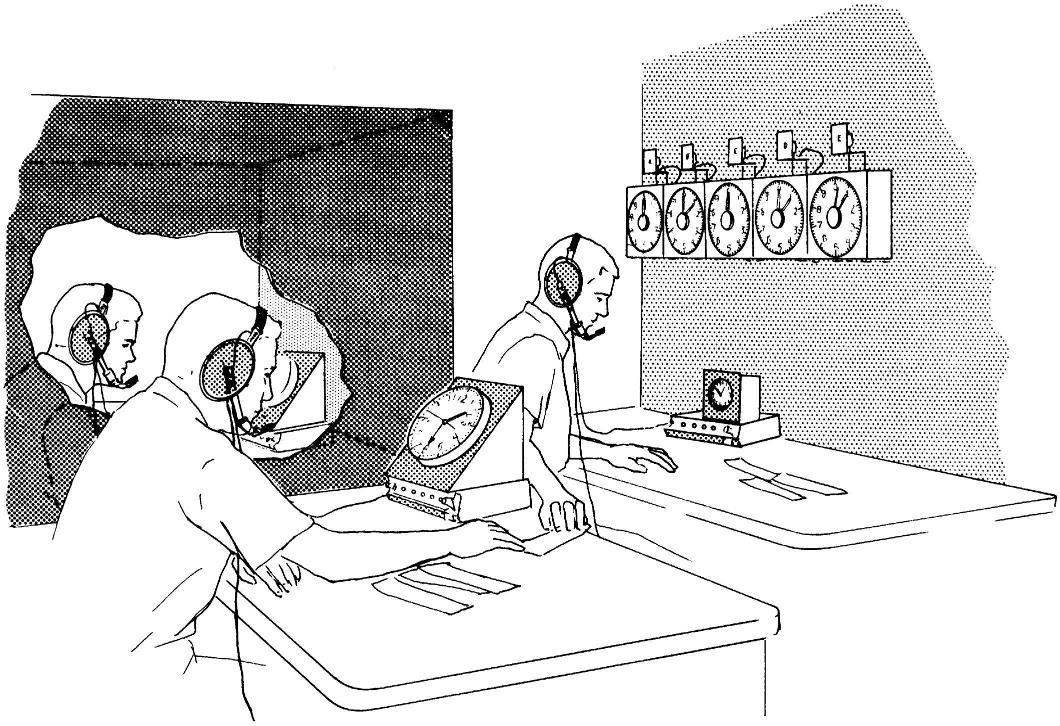


Fig. 9

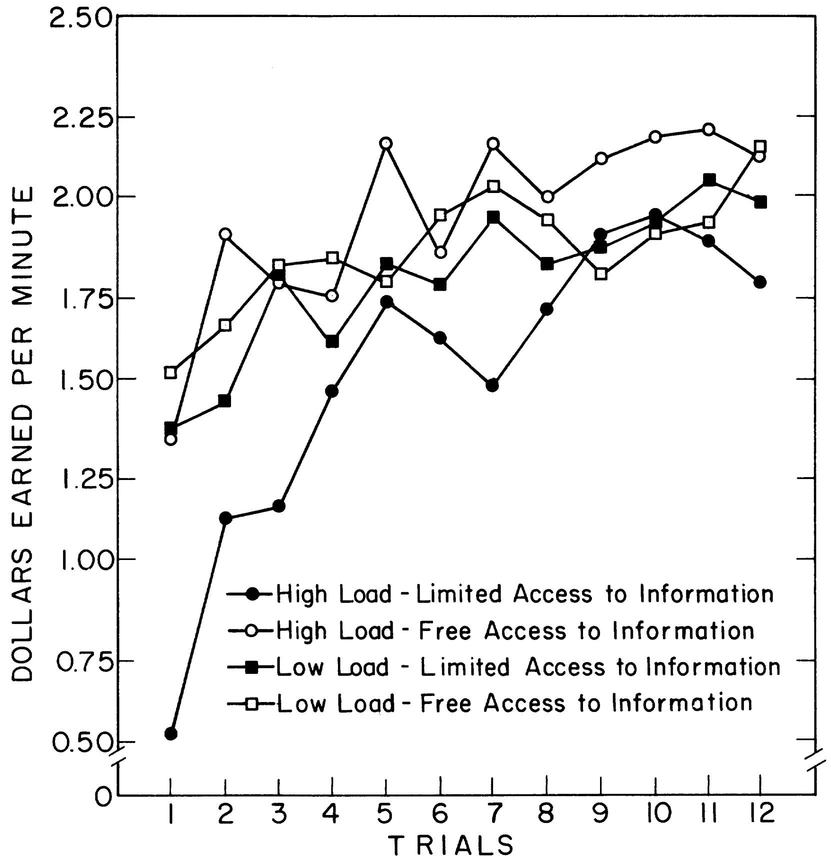

2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0
DOLLARS EARNED PER MINUTE
High Load - Limited Access to Information
High Load - Free Access to Information
Low Load - Limited Access to Information
Low Load - Free Access to Information
1 2 3 4 5 6 7 8 9 10 11 12
TRIALS

Fig. 10

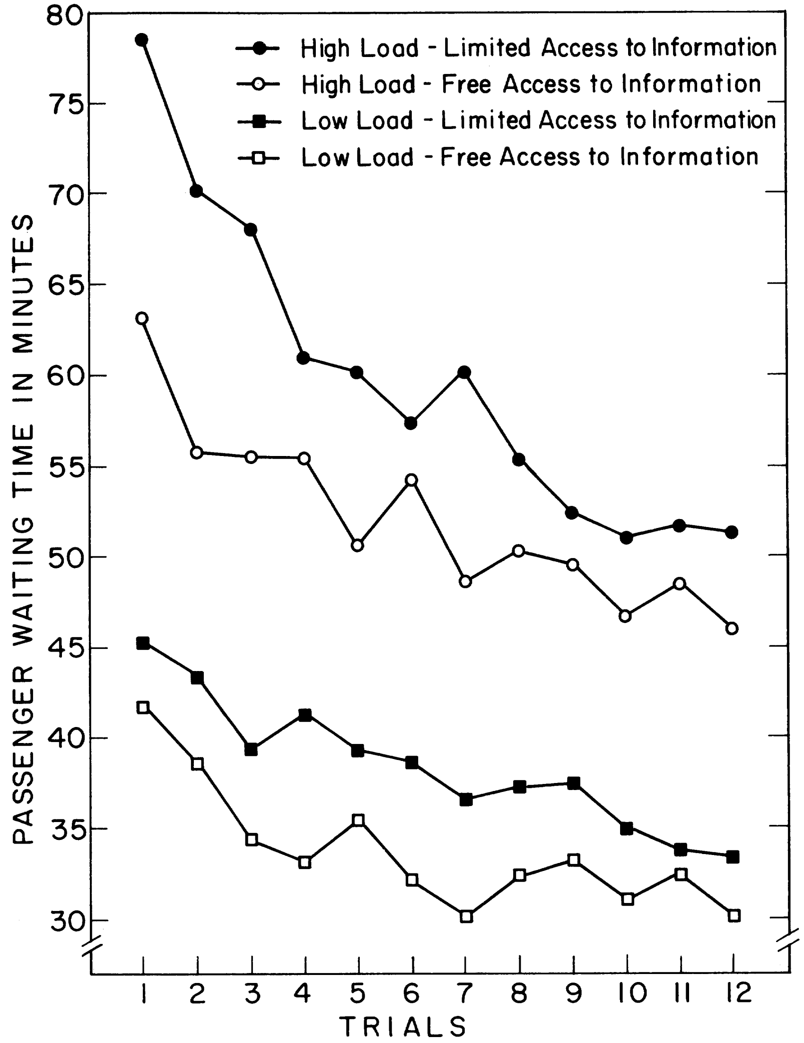

80
75
70
65
60
55
50
45
40
35
30
PASSENGER WAITING TIME IN MINUTES
High Load - Limited Access to Information
High Load - Free Access to Information
Low Load - Limited Access to Information
Low Load - Free Access to Information
1 2 3 4 5 6 7 8 9 10 11 12
TRIALS

Fig. 11

free access to information appeared to be due chiefly to more effective and more flexible load-balancing procedures and other acts of collaboration in performing routine-task functions. These collaborative procedures enabled the work to be done more rapidly and cabs to be assigned more quickly to waiting passengers. This increased speed of decision making was accomplished without any increase in mechanical (bookkeeping, etc.) errors, or any loss in the efficiency of decisions. Also, under conditions of free access to information, teams were able to learn faster, thus increasing their speed of performance without sacrificing accuracy, and indicating a more rapid adoption of an effective team organization for decision making. It had been hypothesized that under very heavy load conditions, the free-access situation might lead to some confusion and inefficiency as compared to the use of a more fixed or routine procedure which would be forced by the conditions of limited information access. This condition did not develop, perhaps because the performance of teams was somewhat better than had been predicted from preliminary runs. It is possible that under much higher load conditions some amount of breakdown might have been found. In general, the results strongly support the general hypothesis of the advantage deriving from flexibility and free access to information in information processing work performed under stress for speed.

CURRENT AND PROJECTED RESEARCH ACTIVITIES

Captain Austin Kibler's proposed thesis work, dealing with the capacity of individuals for filtering and monitoring activities in information processing, has continued at a relatively low level for the past six months. Apparatus has been constructed for the programming of signals, and considerable background work has been done in reviewing and interpreting the literature on alertness and monitoring behavior. Captain Kibler is planning to initiate intensive research in this area in the near future. He is working toward a Ph.D. in psychology while assigned to The University of Michigan by the U. S. Air Force Institute of Technology.

The effects of augmented feedback on information-handling performance, proposed as one of the original areas of investigation, is now being studied in two related experiments which are carried on by three first-year graduate students, Irving Biederman, Howard Egeth, and Edward Smith. These two closely related studies compare conventional feedback, which is usually given verbally at the end of a session, with immediate analytic feedback concerning both speed and accuracy of response. The theory under study relates these feedback effects to (a) the level of difficulty of the task, and (b) the charactistics of subjects with respect to need achievement and anxiety relating to failure. A discrete information-processing task is being employed. Data collection is under way, and the methodology appears to be an effective one for study of this particular problem. One interesting side effect has been uncovered incidental to the development of this methodology. It would appear that in continuous tasks achievement feedback may compete for limited human information-processing channel capacity. Thus the effects of augmented feedback may be considerably greater in a discrete task where there is a delay between events. The effects of achievement feedback in terms of a theory of competition for channel capacity may be investigated in a later experiment.

Some of the earlier work on ability of individuals to change set, particularly ability to adjust to variations in stimulus redundancy, indicates the plausibility of a sequential stimulus-sampling theory of information processing. This formulation appears promising at the present time, but has not been developed to the point where a complete exposition is warranted. An experiment is under way in the study of adjustment mechanisms in responding to redundant sequences. This is an extension of two studies already submitted for publication.

As part of a series of television films being prepared by The University of Michigan Television Studios, and featuring work of various members of the Department of Psychology, one 30-minute film was prepared (at no cost to the project) covering some of Dr. Fitts' work on human reaction time and information processing. Acknowledgment is made in the film of the fact that the majority of this research is being supported by the Air Force Office of Scientific Research. It is planned to submit a copy of this film for review as a separate part of this progress report.

Work during the coming period will emphasize the further integration of theory and the preparation of reports of completed series of studies.