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by Earl A. Alluisi and Ben B. Morgan, Jr.

Prepared by
UNIVERSITY OF LOUISVILLE
Louisville, Ky.

for

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Abstract

An investigation of the effects of practice and operator work load on the acquisition and performance of a code-transformation (COTRAN) task are reported. The COTRAN task was developed previously (cf. Alluisi & Coates, 1967) to provide a means for obtaining performance measurements of that part of intellectual functioning which is typically called "non-verbal mediation"; it follows the problem-solving paradigm.

The experiment was conducted in two phases. During the first, or acquisition phase, 27 COTRAN problems were solved on each of four (Group-4, with four subjects), eight (Group-8, with twenty subjects), or twelve (Group-12, with four subjects) successive days. Performance reached asymptotic levels in four to six sessions, in general, and the differences in final levels of performance of the three groups (4, 8, and 12) were not statistically significant.

Additional analyses of the data of Group-8 indicated that (1) the factorial structure of COTRAN performance remained constant across the eight sessions of practice, as well as across the different subjects and experimental conditions employed here and in a previous study; (2) the levels of performance increased with practice through four to six sessions, and asymptotic levels were indicated with error-based measures earlier than with time-based measures of performance; and (3) the effects of transformation complexity were evidenced in post-acquisition skilled performance, but not at earlier stages of practice.

During the second, or transfer phase of the study, each of the 28 subjects solved 27 COTRAN problems on each of five successive days while time-sharing the COTRAN task with different combinations of tasks selected from a multiple-task performance battery. The results indicated that skilled COTRAN performance is sensitive to at least two or three levels of work-load stress, and that different subjects may tend to adopt different strategies in time-sharing the COTRAN task with other tasks.

Foreword

This report was prepared by Dr. Earl A. Alluisi, Executive Officer for Planning and Development and Professor of Psychology, and Dr. Ben B. Morgan, Jr., Research Associate, both of the University of Louisville, Louisville, Kentucky, 40208. The research program under which this work was completed is supported by the National Aeronautics and Space Administration under Research Grant No. SC/NGR-18-002-008, "Performance Measurements of Nonverbal Mediation," monitored by the Human Performance Branch, Biotechnology Division, Life Sciences, NASA Ames Research Center, Moffett Field, California.

Part of the research reported is based on a dissertation prepared by the junior author under the direction of the senior author and presented in partial fulfillment of the requirements of the degree, Doctor of Philosophy, at the University of Louisville. The authors wish to express their appreciation to Drs. W. Dean Chiles, Glynn D. Coates, Emerson Foulke, Milton H. Hodge, Thomas H. Koltveit, Richard P. Smith, and John B. Thurmond for their interest, guidance, and helpful suggestions during the course of the research, and to Mr. Karl E. Rothrock for his assistance in the design and construction of the apparatus.

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Introduction

The assessment of human performance in operational systems is probably the most difficult and important current requirement in human factors engineering. The need is evidenced not merely by the desire to evaluate operator performance, but also because performance assessments are fundamentally related (as criterion measures) to further advances in numerous other areas. For example, final validations of selection techniques, training programs, and human-engineered system designs depend on the measurement and assessment of operator performance, as do also evaluations of stress effects, measurements of performance decrements, and the establishment of optimum operating conditions.

The applicable research on performance assessment can be classed into three major approaches; namely, simulation techniques (cf. Grodsky, 1967), the use of individual laboratory tests based on factor-analytically identified components of skill (cf. Fleishman, 1967; Parker, 1967), and the measurement of time-shared multiple-task performances in synthetic work situations (cf. Alluisi, 1967). All three approaches have advantages and disadvantages, and each has contributed something to the development of performance-assessment techniques (see Chiles, 1967), but it is with the third approach--the synthetic-work technique--that the present research is concerned.

Synthetic Work and the MTP Battery

The development of the synthetic-work technique began in 1956 when the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, instigated a program of research on crew performance. Much of the initial research was conducted under contract at the Human Factors Research Laboratory of the Lockheed-Georgia Company, Marietta, Georgia, and the work has been carried on subsequently at other institutions, including the Performance Research Laboratory at the University of Louisville. Since the results of most of this research have been summarized elsewhere (Alluisi & Chiles, 1967; Chiles et al., in press), only a brief resumé will be given here to indicate the relevance of the present research to the broader area of performance assessment.

The plan that developed was to conduct research on crew performance applicable to advanced systems of a general class. No specific system was to be simulated directly, but it was hoped that a generalized system could be devised in terms of the functions required of the operators. It was predicted that the data obtained would be applicable to a wide range of specific systems in which the same or similar operator functions were employed.

It was decided at an early date that major emphasis would be placed on operator performance of the functional aspects of mission-related tasks, and a group of tasks was assembled; a crew compartment was designed and constructed, as were also the performance panels, the programming and scoring apparatus, and the experimenters' control consoles (Adams, 1958). Then, an initial experiment was conducted to answer questions concerning certain technical matters such as reliability and intertask correlations (Adams et al., 1959).

Among the variables investigated in later studies were: (1) the work-rest cycle (8-hours on duty and 8-hours off, 6-6, 4-4, and 2-2), (2) the work-rest ratio (1:1, 2:1, and 3:1), (3) the operator work load, (4) the addition of group-performance tasks to the battery of tasks that had been developed, (5) the total duration of the period of a crew's confinement in a mock-up of a small crew compartment (4 hours, 4 days, and 12, 15, and 30 days), (6) the effects of two days of sleep loss on performance under two work-rest schedules (4-2 and 4-4), (7) the elementary relations between the performance measures obtained and two biomedical measures, and (8) samples of subjects representing different populations (college students, including ROTC and Air Force Academy cadets, operational B-52 crews, and Air Force Officers newly graduated from pilot training schools). The results of these studies have been reported in USAF technical reports (Adams & Chiles, 1960; 1961; Alluisi et al., 1962; 1963; 1964; Hall et al., 1965) and, as indicated earlier, they have been summarized elsewhere (Alluisi & Chiles, 1967).

In the course of the research, a multiple-task performance (MTP) battery of tests was developed for use under controlled laboratory conditions. The MTP battery presents a synthetic work situation to its operators or subjects. Among other uses, it has been employed to study the behavioral effects of infectious diseases (Alluisi & Fulkerson, 1964; Alluisi & Thurmond, 1965; Alluisi et al., 1966; 1967; Thurmond & Alluisi, 1967).

The battery includes tasks that were designed to measure: (1) watchkeeping, vigilance, and attentive functions, (2) sensory-perceptual functions, (3) memory functions, both short- and long-term, (4) communication functions, including the reception and transmission of information, and (5) procedural functions that include such things as interpersonal coordination, cooperation, and organization. The battery as it currently exists has essentially no measures of (6) perceptual-motor functions, but research is in progress elsewhere to develop a suitable task for this purpose. Finally, the battery has provided only indirect measures of (7) intellectual functions, and the present research has been conducted to correct this deficiency.

Nonverbal Mediation and the COTRAN Task

In order to develop a task that would provide sensitive and reliable measures of a subject's intellectual performance, previous research indicated that the task would have to meet certain criteria (Alluisi & Coates, 1967). Specifically, (1) it would have to be based on elements of the problem-solving paradigm in order to provide the desired measurements of intellectual functioning, and (2) it would have to allow for an adequate number of both measures and replications during reasonably short intervals of time in order to provide maximum reliability. Finally, (3) it would have to permit the experimental control of important variables associated with the subject's performance (e. g., the time at which the information sufficient for a solution is presented, the number of ways in which the solution can be reached, and the number of correct solutions per problem).

The task that was designed to meet these requirements was a modification of the "code-lock solving" task that is used as a group-performance task in current versions of the MTP battery (cf. Alluisi et al., 1962, pp. 5-6; Alluisi & Fulkerson, 1964, p. 14). It is an individual, rather than a group-performance task; it has been called the COTRAN task (for CODe TRANsformation). It was designed also to meet certain criteria of face validity, sensitivity, engineering feasibility, reliability, flexibility, work-load variability, trainability, and control-data availability as defined elsewhere (Alluisi, 1967). The task is intended to provide performance measures of that part of intellectual functioning which is typically called "nonverbal mediation."

The working elements of the COTRAN task are displayed to the operator on a response board and information panel as shown in Figure 1 (p. 4). These elements consist of five response keys arranged to fit the fingers of the right hand, three primary indicator lights (red, amber, and green) on a sloping panel, and three secondary indicator lights (all blue) on the lower front of the display. The task is performed in three phases.

In phase I, the operator is required to discover, by means of a systematic trial-and-error search pattern, the proper sequential order for depressing the five response keys (one for each finger of the right hand). The three indicator lights on the sloping panel provide the information necessary for the discovery of the correct sequence. Illumination of the red light is the signal that a sequence is present and ready to be solved. The amber light is illuminated when the operator depresses any of his response keys, thereby indicating that his response has been registered. When the response key is released, the amber light is extinguished; the red light remains illuminated unless the key that was depressed is the "correct" first response. If it is the correct first response, then the red light is extinguished at the same time as the amber light, and it will remain extinguished until an "incorrect" (i. e., out-of-sequence) response is made. When this occurs, the red light is re-illuminated, and the programming apparatus resets automatically to the beginning of the sequence. In order to recommence the search for a solution, then, the correct first key must be depressed first, the correct second response key must be depressed next, etc. When all five response keys have been depressed in the correct order, the green light is illuminated to indicate that the sequence presented in phase I has been completed.

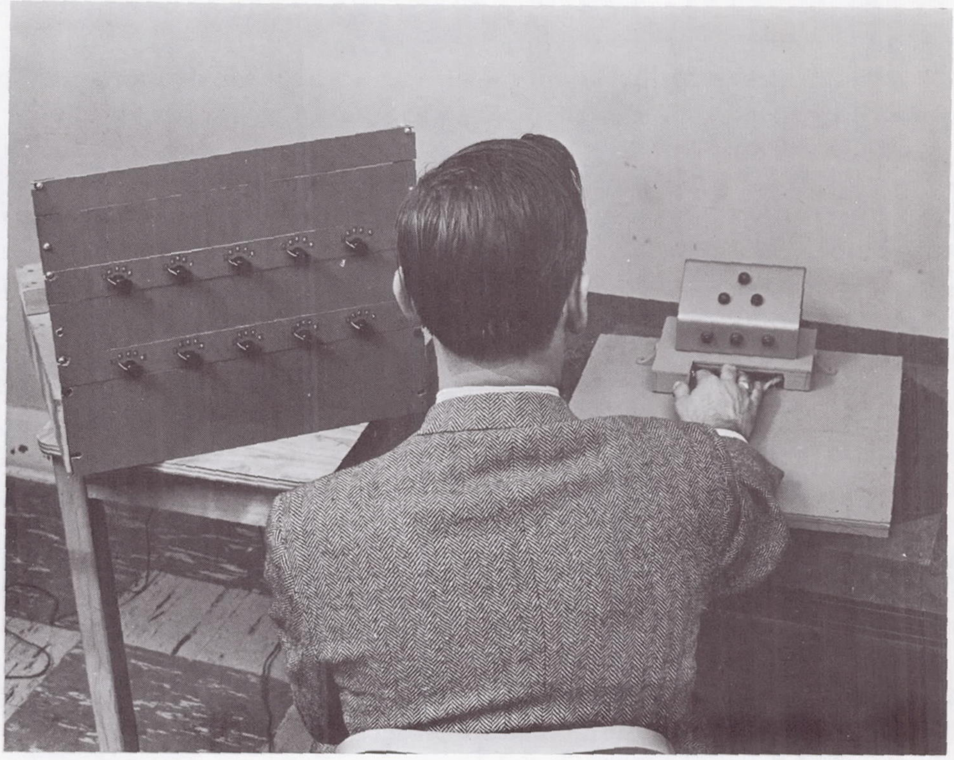

Figure 1. --Photograph of the COTRAN apparatus showing the subjects' memory aids, information panel, and response board.

Following a between-phase pause of 30 sec., the green light goes off, the red light comes on, and the operator is presented with phase II of the problem. Phase II is identical to phase I, except that it involves a different sequence. The left-most blue light is lit during phase I, the second or middle one is lit during phase II, and the right-most blue light is lit during phase III, which begins immediately upon completion of phase II.

During phase III, the operator is required to deduce, from the sequences (solutions) of phases I and II, the transformation that must have been applied to the sequence of phase I in order for it to have generated the sequence of phase II. That is to say, he has to determine how the phase-I sequence would have had to be changed in order for it to have produced the phase-II sequence. The operator is then required to apply the deduced transformation to the phase-II sequence in order to predict the solution to a third key-pressing sequence; i.e., he has to predict a third sequence and test his prediction by applying it.

Although additional descriptive material, including a discussion of some of the characteristics of the COTRAN task, has been given in a previous report

(Alluisi & Coates, 1967, pp. 5-9), two of the parameters of the task will be described here.

First, one possible parametric dimension of the COTRAN task is the complexity of the transformation, or the number of elements involved in the transformation. Given the restriction that no key can appear twice in the same sequence, there are 120 different sequences that can be presented in phase I. Also, there are 119 different sequences that can be presented in phase II, given that the sequences of phases I and II must differ. A breakdown of these 119 sequences indicates that there are ten sequences which change only two elements of the phase-I sequence; stated differently, there are only ten 2-element transformations. Likewise, there are twenty 3-element transformations, forty-five 4-element transformations, and forty-four 5-element transformations. Since the operator must deduce the transformation and apply it to the phase-II sequence in order to arrive at the final solution in phase III, the difficulty of the phase-III solution should be related to the complexity or number of elements involved in the transformation employed.

A second parametric dimension of the COTRAN task is the number of memory aids available to the operator. It should be apparent that the COTRAN task imposes a considerable load upon the operator's memory capacity; he must hold in memory not only the discovered phase-I sequence, but also the phase-II sequence and the current position of his solution attempts in phase III. This memory load can be lessened by providing the operator with one memory aid (on which to record the phase-I sequence), two memory aids (for phases I and II), or three memory aids (for phases I, II, and III). Two memory aids were shown with the COTRAN apparatus in Figure 1 (p. 4).

Both of these parameters of the COTRAN task have been used in previous experimentation (Alluisi & Coates, 1967). In the first of two experiments, 90 operators worked at the COTRAN task under one of a set of six conditions which represented the factorial combination of two memory-aid conditions (one or two aids available) with three transformation-complexity conditions (three, four, or five elements per transformation). Seventy-two measures of COTRAN performance were factor analyzed, and five COTRAN factors were identified. Nine measures were selected to represent the five factors, and with these measures it was found that performance with two memory aids was better than with one. The factorial structure was the same under the two conditions, but learning was significantly improved under the two memory-aid condition. Differences among the three levels of transformation complexity were not statistically significant.

In the second experiment, 84 operators each completed 18 COTRAN problems as well as a set of paper-and-pencil tests of intellectual abilities and personality. A factor analysis of 75 measures resulted in the identification of five COTRAN factors (the same as in the first experiment) and three additional factors--one for verbal intelligence, and two for personality characteristics. The results also indicated that the COTRAN task provides measures of nonverbal mediation (cf. Alluisi & Coates, 1967, p. 30) and that the COTRAN measures of problem-solving behavior are suitably reliable (Alluisi & Coates, 1967, p. 29). Practice effects were clearly evidenced in the solutions of the 18 COTRAN problems, but asymptotic levels of performance were not reached. Differences among the three levels of transformation complexity were, again, not statistically significant, but this may have been because skilled performance--i.e., asymptotic performance--was not obtained with the number of problems (18) completed by each operator.

Experimental Questions: Practice and Work-load Effects

Since the purpose behind the development of the COTRAN task is related to its use in the MTP battery, the present investigation was planned to begin studying the ways in which the two are to be combined. For example, because the tests in the MTP battery can be presented in different combinations, different work loads are imposed on the operator. The effects of adding the COTRAN task to the multiple-task performance situation need to be assessed, therefore, both with regard to the effects of COTRAN on the other tasks and the effects of the MTP tasks on COTRAN performance and structure. Also, since asymptotic levels of performance (or "skilled performance") have not been attained in prior experimentation, the present investigation included a rather detailed study of the acquisition phase--i.e., a study of the effects of practice both on COTRAN performance and on the transfer of the skill developed in working the task alone to the situation in which it is time-shared with other tasks.

The four general questions that were to be answered by the present study are as follows:

(1) Do changes in the factorial structure of the COTRAN task take place during acquisition of the problem-solving skill, and if so what are these changes?

(2) Do the gains in performance with practice distribute themselves equally and uniformly over the nine measures of the five COTRAN factors, and if not how do they differ?

(3) Is COTRAN performance affected by transformation complexity at any level of acquired skill, and if so how, at what level(s), and to what degree?

(4) What are the effects of work-load stress (imposed by the time-sharing of different combinations of tests from the MTP battery) on skilled (post-acquisition) COTRAN performance, and what are the effects of time-sharing the COTRAN task on the performance of the MTP tasks? How does the amount of COTRAN practice affect each of these?

Method

The present investigation was conducted in two separate phases. The first or acquisition phase was concerned with the effects of practice on COTRAN performance, whereas the second or transfer phase had to do with the transfer of skilled COTRAN performance to conditions in which the task was time-shared with various combinations of tests from the MTP battery.

A total of 28 subjects was randomly divided at the outset into three groups that were maintained throughout both phases of the experiment (Groups 4, 8, and 12). The major experimental group (Group-8) consisted of 20 subjects randomly divided into five subgroups of four each, whereas each of the other two groups consisted of four subjects. The groups were treated identically except for the number of COTRAN problems solved during the acquisition phase (4, 8, or 12 sessions of practice, respectively). In all cases, two memory aids were provided in order to maximize both the acquisition rate and the final level of skilled performance attained. The two phases of the experiment will be described separately.

The Acquisition Phase

General. --The major purpose of the acquisition phase was to measure the effects of practice on COTRAN performance. Practice was to be continued until a stable asymptotic level of performance had been attained. The results of pilot studies had indicated that performance would begin to stabilize after the solution of about 125 COTRAN problems. Thus, it was decided that at least this number of problems would be needed for the major condition, and the 20 subjects in Group-8 solved 27 problems per session during each of 8 successive sessions (216 problems in all). The four subjects in Group-4 and the four in Group-12 also solved 27 problems per session, but for 4 and 12 successive sessions, respectively (108 and 324 problems). In all cases, a subject's successive sessions occurred on successive days (weekends included), one session per day. The different amounts of practice permitted a comparison of transfer effects during phase II of the study.

A secondary purpose of the acquisition phase was to test for any effects that transformation complexity might have on skilled COTRAN performance. Thus, the order of presentation of three-, four-, and five-element transformations was counterbalanced within each session of 27 problems (9 replications of problems at each of the three levels of transformation complexity).

Apparatus. --The apparatus consisted of three basic components used by the subject (response, information, and memory units) and two components used by the experimenter for programming and scoring. The positioning of the response keys was determined from 10 male and 10 female subjects on the basis of measurements of the natural positioning of the fingers of the right hand when at rest; the exact dimensions are given elsewhere (Coates, 1966, Fig. 2).

The six, 1/2-in. diameter jeweled indicator lights on the subject's information panel were mounted as previously shown in Figure 1 (p. 4). The blue lights were used to indicate the phase of the problem on which the subject was working (I to III, from left to right), whereas the red, amber and green lights provided the information necessary for the solution of each phase.

The subject's response and information units were mounted on a 30-by-20 in. response board which in turn was mounted on a 30-by-30 in. table. The top of the table was 27 in. above the floor.

The memory unit enabled the subject to record his phase-I and phase-II sequences after he had discovered them. As was shown in Figure 1 (p. 4), the unit included two memory aids, each of which consisted of five, 5-position, 1-in. diameter, rotary switches. Each switch could be set to point to any of the five numerals, 1, 2, 3, 4, or 5. The five rotary switches on a memory aid corresponded to the five keyboard positions on the subject's response board: the left-most switch to the thumb position, the next left-most switch to the index-finger position, etc. At the end of phase I (or phase II), the subject would set each of the rotary switches on the upper (or lower) memory aid to the numeral that indicated the sequential position of the corresponding key (or finger) in the correct key-pressing sequence. For example, the middle rotary switch set on "4" would indicate that the middle finger was the fourth key-press in the sequence. The upper memory aid was used for the phase-I sequence, and the lower was used for that of phase II. The switches were mounted on a vertical panel 11-by-19 in., on 3-in. centers, with the center switch of the first row 4 in. from the top of the panel. The panel faced the subject from the left of the COTRAN information display and was angled about 45-deg. from normal to facilitate its use.

The experimenter's programming unit consisted of three banks of five, 5-position rotary switches--one bank for each of the three phases of a problem. The experimenter programmed the correct sequences on these banks of rotary switches, which were connected electrically to a stepping switch and a series of relays that served to score the correctness of the subject's responses. Thus, in conjunction with the programming unit, the scoring unit permitted the experimenter to monitor accurately the subject's performance. The subject's total responses, errors, and response times (to the nearest 0.1 sec.) for each phase were recorded on electromechanical counters.

Subjects and experimental design.--The subjects were 28 undergraduate male students at the University of Louisville. They were volunteers from the Naval and Air Force ROTC units who were paid for their participation in the study. The subjects ranged in age from 18 to 25, with a median of 19 years.

Each subject served in one experimental session on each of 4, 8, or 12 successive days (for Groups 4, 8, or 12, respectively). He solved nine blocks of three problems during each session, or a total of 108, 216, or 324 problems depending on the group condition to which he was assigned. Each block of problems consisted of a three-, four-, and five-element transformation; the order of presentation of the three transformation complexities was counterbalanced throughout all sessions.

Procedure. --The subject and his apparatus occupied a 7-by-14-ft. experimental room in which an overhead florescent light fixture provided ambient illumination. The experimenter's apparatus was placed in an adjoining room and was connected to the subject's by a single cable. Approximately 70 dB of broadband noise were used in the experimental room to mask the sound of the programming unit and to isolate the subject from other extraneous noises.

During his first session, each subject received a standard set of instructions (reproduced exactly in Morgan, 1968, Appendix A), and then solved 27 COTRAN problems. The initial session was usually of about 2-hr. duration; each subsequent session of 27 COTRAN problems lasted from 60 to 90 min. Subjects were instructed to solve the COTRAN problems as quickly as possible, but to keep errors at a minimum.

For each problem, a phase-I sequence was randomly selected from the 120 possible sequences and entered by the experimenter on the first bank of programming switches. Then the experimenter selected at random one of the transformations from the appropriate subpopulation (of three-, four-, or five-element transformations) and applied it to the phase-I sequence in order to determine the phase-II sequence. He entered this sequence on the second bank of programming switches, then applied the transformation to that sequence in order to produce the phase-III sequence that was entered on the third bank of switches. Each problem (and phases I and II of a given problem) was separated by a 30-sec. "green-light" interval or "no response" delay.

The Transfer Phase

General. --Each of the 28 subjects served in five sessions during the transfer phase of the study. The first session for a given subject began approximately one month after the end of his acquisition-phase sessions. The month delay between phases was nearly constant for all subjects since they were tested in the same order that was employed during acquisition.

The primary purpose of the transfer phase was to assess the effects of work-load stress on skilled COTRAN performance. The subjects in Group-8 were used for this purpose; i.e., these 20 subjects were divided at random into five subgroups of four subjects each, and each subgroup was assigned to a different work-load condition. The five conditions were produced by using different combinations of tasks from the MTP battery; namely, (1) three watchkeeping tasks (warning-lights, blinking-lights, and probability monitoring), (2) target identifications (TID), (3) arithmetic computations (MATH), (4) the watchkeeping tasks plus TID, and (5) the watchkeeping tasks plus MATH. These combinations represented increases in the amount of "cognitive processing" required of the subjects. Since COTRAN performance is largely problem-solving behavior, dependent on intellectual functioning or nonverbal mediation, the increased time-sharing requirements placed on the subject were expected to produce detrimental effects at some point(s) along the dimension of the work-load stress.

A secondary purpose of the transfer phase was to determine how the amount of practice obtained during the acquisition of the COTRAN skill affected the performance of the task at one selected level of work-load stress. Thus, Group-4 (with four sessions of practice) and Group-12 (with twelve sessions) were required to perform under the TID condition of work-load stress--a condition also employed with one of the subgroups from Group-8 (with eight sessions of practice).

Apparatus. --The COTRAN apparatus was identical to that used in the acquisition phase. In addition, the MTP battery was employed--the operator panel by the subject and the necessary programming and scoring equipment by the experimenter.

As indicated previously, six tasks can be presented with the MTP battery. The tasks are displayed on an operator panel the face of which is shown schematically in Figure 2. Since all the tasks have been described previously, they will be identified here without repetition of the full descriptions given elsewhere (Adams & Chiles, 1960; 1961; Alluisi et al., 1962; 1963; 1964; 1967).

Three tasks are used to measure the operator's performance of watchkeeping, vigilance, and attentive functions (blinking-lights, warning-lights, and probability monitoring). These tasks require the operator to respond to the relatively infrequent occurrence of changes in the states of certain visual displays. In the warning-lights task (located at the extreme left of the panel), the operator is required to respond by turning a green warning light on should it go off, and a red warning light off should it go on. Blinking-lights monitoring (located at the extreme right) requires that he respond to an arrest of alternation of the blinking of the two amber lights. The probability-monitoring task (presented by the four meters along the top of the panel) is somewhat more difficult than the other two watchkeeping tasks. It requires an integration over time of random fluctuations of the pointers on the four semicircular scales. The pointer settings are normally distributed with a mean of zero; the operator is required to respond to relatively infrequent shifts in the mean of this distribution.

The remaining three tasks are used to measure memory functions (arithmetic computations), sensory-perceptual functions (target identifications), and procedural functions (code-lock solving). The code-lock solving task was not used and will not be discussed here.

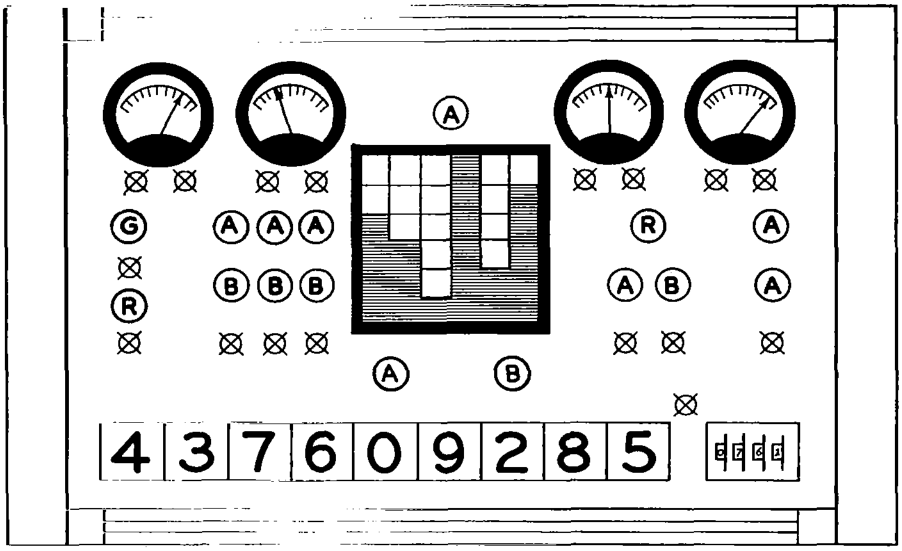

Figure 2. --Front of the MTP operator panel. Letters in circles represent indicator lights, A--Amber, B--Blue, G--Green, and R--Red: the smaller circles with crossing diagonals represent push-buttons.

The arithmetic-computation (MATH) task (located along the bottom of the panel) presents a horizontal display of three, 3-digit numbers, or nine digits in all. The operator is required to add the first 3-digit number to the second, and then to subtract the third 3-digit number from the sum. No memory aid is permitted, and the task is force-paced at a rate of three problems per minute.

The target-identification (TID) task (located in the center of the panel) presents a "target" image which resembles a solid bar graph, then successively two similar "choice" images (either or both of which might be rotated 0, 90, 180, or 270 deg. from the normal positioning of the target). The operator judges whether the first, the second, or neither of the two choice images is the same as the previously displayed target image, irrespective of orientation. This task is force-paced at a rate of two problems per minute.

Subjects and experimental design. --The same 28 subjects trained during the acquisition phase of the study served in this transfer phase. The subjects had been arranged into seven subgroups of four subjects each. Each of the five Group-8 subgroups served under a different work-load condition, whereas Groups 4 and 12 served only under the TID work-load condition. Thus, two experimental designs were employed. In the first, the concern was with the effects of work-load stress on the skilled COTRAN performance which was based uniformly on 8 sessions of practice: the five work-load conditions were combined factorially with the five performance sessions of the transfer phase, and four subjects were nested in each of the five work-load levels. In the second design, the concern was with the effects of the total amount of COTRAN practice on the performance of the task under a single work-load condition (with the TID task): three practice levels (4, 8, and 12 sessions) were combined factorially with the five transfer sessions, and four subjects were nested in each of the three levels of practice.

Procedure. --The COTRAN apparatus and the MTP operator panel are shown in Figure 3 (p. 13) as they were used by the subjects during the transfer phase of the study. All other physical conditions of the study, including the experimental room and its lighting, the 70-dB ambient noise, and the location of the experimenter and his apparatus in an adjoining room were identical to the conditions of the acquisition phase.

Each subject served for five sessions--one on each of five successive days. Training on the MTP tasks was provided during the first session. That is to say, at the beginning of his first transfer-phase session, each subject was trained on the MTP task(s) which had been assigned to his subgroup. Instructions were given separately for each task, and the subject was permitted to work from three to five familiarization problems prior to the beginning of the training. During the remainder of the session, the subject worked at the MTP task(s) assigned for three 30-min. periods separated by 5-min. rest intervals.

The second transfer session was used as a COTRAN "retraining" session as well as a practice session for the work-load stress condition assigned. Because approximately one month had elapsed since each subject's last COTRAN-acquisition session, each was required to solve 27 COTRAN problems prior to any practice in combined performances of both the COTRAN and the assigned MTP tasks. The "retraining" data permitted a test for any changes in COTRAN performance that might have taken place during the month without practice. The data also provided a baseline level for use in comparing the COTRAN performances obtained during the remaining sessions of the transfer phase--the sessions during which the COTRAN and MTP tasks were time-shared. During the remainder of the second session, each subject was required to solve nine COTRAN problems while concurrently operating the MTP task(s) assigned to his subgroup. The data of this latter part of the session have not been analyzed, but rather have been filed away as relevant only to early practice in the time-sharing of COTRAN and MTP tasks.

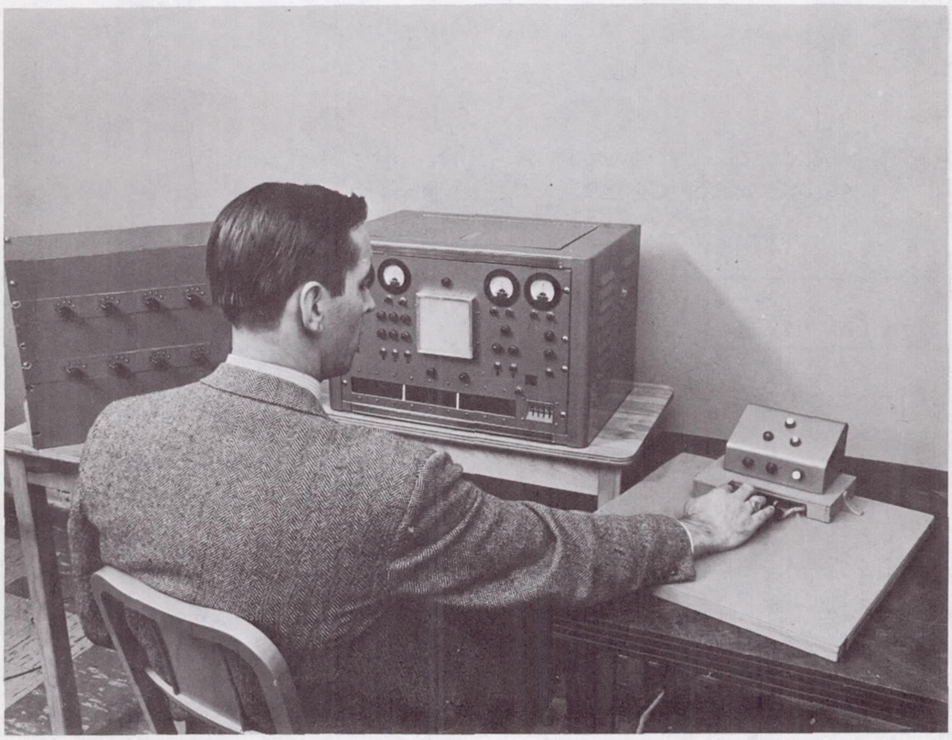

Figure 3. --Photograph showing the arrangement of the COTRAN and MTP apparatus during the transfer phase. The MTP operator panel is located in the center, the COTRAN memory aids are on the left, and the information panel and response board are on the right of the seated operator.

The remaining three sessions provided the principal performance data of the transfer phase. During each session, each subject was required to solve 27 COTRAN problems with concurrent operation of the assigned MTP task(s). Subjects were instructed to do their best on each task, and to weigh none as more important than another. Each of the five transfer-phase sessions lasted from 60 to 90 min.

Results

The results of the acquisition and transfer phases are presented separately in this section. First, however, the nine measures employed in these analyses are defined in Table 1 (p. 14). The factor loadings of the nine measures on the

Table 1

Identification and Definition of the Nine Measures of COTRAN Performance Employed

Measure Number and Identification	Algebraic Definition*
1. --Ratio of the number of phase-I sequences completed to the total time in phase I of the problems	(S-1)/(TT-1)
2. --Ratio of the number of phase-I and phase-II sequences completed to the total time in phases I and II	(S-12)/(TT-12)
3. --Ratio of the number of errors in phases I and II to the total time in these two phases	(E-12)/(TT-12)
4. --Ratio of the errors in phase III to the mean errors in phases I and II	2(E-3)/(E-1)+(E-2)
5. --Ratio of the errors in phase III to the total number of phase-III sequences completed	(E-3)/(S-3)
6. --Ratio of the total time in phase III to the mean of the total time in phases I and II	2(TT-3)/(TT-1)+(TT-2)
7. --Ratio of the total time in phase III to the number of phase-III sequences completed	(TT-3)/(S-3)
8. --Ratio of the number of phase-II sequences solved to the total time in phase-II solutions	(S-2)/(TT-2)
9. --Ratio of the number of phase-II sequences completed to the total number of errors in phase-II solutions	(S-2)/(E-2)

*Abbreviations employed are as follows: E for errors or resets, TT for total time, and S for sequences. The numeral(s) connected with a hyphen to an abbreviation indicates the phase(s) of the problems to which reference is made. Thus, "S-1" represents the number of phase-I sequences completed, and "E-12" represents the number of resets in phases I and II. Additional information concerning these and the other measures of COTRAN performance used previously is given elsewhere (Alluisi & Coates, 1967, pp. 8-9 & 14-15).

five COTRAN factors previously identified (Alluisi & Coates, 1967) are given in Table 2. The mean value of each measure (averaged over the 27 COTRAN problems per session) was computed for each subject, and these means were used as the basic data of the analyses reported below.

The Acquisition Phase

The data of the eight acquisition-phase sessions were included in three sets of analyses directed at the first three general experimental questions listed on page 7; namely, (1) a separate factor analysis of the data of each session was computed in order to discover any changes in the factor structure of COTRAN performance with practice, (2) a separate analysis of variance of the data obtained with each measure over the eight acquisition sessions was computed in order to identify significant practice effects and differences among the measures in this regard, and (3) an additional analysis of variance of each of the nine measures in the first and last sessions was computed in order to test the effects of transformation complexity at early and late stages of skill acquisition.

Table 2

Factor Loadings of Nine Measures on the Five COTRAN Factors Previously Identified

Factor	Measure Number#	COTRAN-I* Measure Number	COTRAN-I* Loading	COTRAN-II** Measure Number	COTRAN-II** Loading
I. General Accuracy	1	28	-.95	25	-.93
	2	30	-.99	27	-.98
II. General Response Rate	3	17	.94	17	.62
III. Errors in Problem Solving	4	1	.80	1	.82
	5	8	.84	8	.88
IV. Time in Problem Solving	6	3	.89	3	.89
	7	65	.91	42	.88
V. Speed and Accuracy in Phase II	8	29	.50	26	.18
	9	40	.83	33	.51

#From Table 1 (p. 14).
*See Alluisi and Coates (1967, p. 18).
**See Alluisi and Coates (1967, p. 25).

Factor structure during acquisition. --The nine measures of COTRAN performance were intercorrelated, factor analyzed, and rotated with use of an IBM-1130 "Statistical System" program that employed the principle-axis method, with the highest off-diagonal correlation as the estimate of communality; the factors were rotated according to the Varimax criterion. Five factors were extracted for each of the eight sessions.

The factor loadings obtained with the data of session 1 (and session 8) are given in Table 3. The measures used to identify the five factors (the underlined loadings in Table 3) are the same as those previously selected (see Table 2, p. 15). The factors are identified below; the identifications are identical to those obtained previously (Alluisi & Coates, 1967, pp. 16-20 & 32).

The first factor is identified by its high loadings on measures #1 and #2. This is a general factor that is highly loaded in terms of sequences completed per unit time in phases I and II, but not in phase III. Since the principal determinant of the number of phase-I and -II sequences completed in a given period

Table 3

Factor Loadings of the Nine COTRAN Measures After Varimax Rotation: Data of Session 1 (and Session 8)*

Measures	Factor				
	I	II	III	IV	V
1	-92 (-95)	02 (04)	-07 (02)	-07 (-07)	14 (07)
2	-75 (-83)	-10 (-18)	-11 (02)	-09 (-12)	59 (47)
3	07 (42)	75 (58)	-07 (02)	-02 (06)	03 (-02)
4	02 (-03)	-19 (-04)	91 (95)	19 (22)	-06 (00)
5	13 (01)	04 (06)	91 (95)	25 (22)	-08 (01)
6	-03 (03)	01 (-01)	23 (23)	96 (97)	00 (-02)
7	18 (15)	02 (02)	22 (22)	93 (95)	-15 (-10)
8	-35 (-45)	-19 (-35)	-11 (01)	-09 (-13)	85 (73)
9	06 (07)	-67† (-63)	04 (00)	-07 (03)	36 (16)

*For ease of reading, the decimal point that should precede each entry has been omitted; the numerals in parentheses are the loadings obtained with the data of Session 8.

†The loading of the comparable measure on factor II in the COTRAN-II report (Alluisi & Coates, 1967, Table 9, p. 25) was erroneously reported without an indication that it should have been a negative value. That is to say, the loading of measure 33 (40) on factor II in the referenced table should have been -.59.

of time is the number of errors or resets produced, factor I can be designated general accuracy (cf. Alluisi & Coates, 1967, p. 32).

The second factor is identified by its high loading on measure #3. This is also a general factor that has no high loadings on the phase-III measures. Although it may appear to be an error-rate factor, factor II is best interpreted as general response rate (cf. Alluisi & Coates, 1967, p. 32), since under the present conditions the number of errors produced in ideal performance is a random variable and the error rate is a direct function of the rate of making the necessary keypressing responses.

The third and fourth factors are specific to phase III: Factor III loads highest on measures #4 and #5 and is identified as errors in problem solving. Factor IV has high loadings on measures #6 and #7; it is identified as time in problem solving.

The fifth and final factor is identified by its loadings on measures #8 and #9. This is a group factor isolated from the more general factors (I and II), and from the other group factors (III and IV) that are specific to phase III, the problem-solving phase. Factor V has been interpreted as speed and accuracy in phase II (Alluisi & Coates, 1967, pp. 19-20).

These data were analyzed further by comparing the factor structures obtained in sessions 1 and 8 with that obtained in the previous COTRAN-II study (Alluisi & Coates, 1967, p. 25). Specifically, the present factor loadings were correlated with the corresponding loadings of the previous study. The coefficients of correlations, as shown in Table 4, indicate that the factor structures of both sessions 1 and 8 are essentially identical to those obtained in COTRAN II, with the sole possible exception of factor V. On the other hand, the low correlations of the factor-V loadings were not entirely unexpected: (1) this is the weakest of all the factors and accounts for less than 5% of the total variance in each case, and (2) the COTRAN-II loadings on factor V were smaller than the loadings of any of the identifying measures of the other four factors (actually, the highest loading of any of the nine measures on the COTRAN-II factor V was .50).

In addition, the factor-V data of sessions 1 and 8 were correlated with the corresponding data of the initial study of COTRAN performance; i.e., with factor V of the COTRAN-I study (Alluisi & Coates, 1967, p. 18). The coefficients of correlation are .761 and .676 for sessions 1 and 8, respectively. Since both these correlations are statistically significant ($df = 7$, $P < .05$), it is concluded that the five factors identified here do not differ from those previously identified, except insofar as they all differ from the atypical factor V of the COTRAN-II study.

The data presented in the last column of Table 4 are coefficients of correlation between the corresponding factors of sessions 1 and 8. These data indicate

Table 4

Coefficients of Correlations Between Corresponding Factors From Sessions 1 and 8 of the Acquisition Phase and From a Previous Study (COTRAN II)

Factor	Conditions Correlated*		
	A-B	A-C	B-C
I	.843	.746	.954
II	.983	.954	.998
III	.818	.839	.990
IV	.967	.953	.994
V	.331	.252	.973

*A--COTRAN II (Alluisi & Coates, 1967, p. 25); B--Session 1; C--Session 8.

that the factors are essentially identical; i.e., the underlying factor structure appropriate to asymptotic COTRAN performance (session 8) is essentially the same as that appropriate to the performance at the beginning of acquisition (session 1). The stability of the factor structure of the COTRAN task over the eight sessions (days) of practice is demonstrated further by the data of Figure 4--the percentage of total variance explained by each of the five factors in each of the eight sessions.[1] The contributions of the factors to the total explained variance are relatively constant across the eight skill-acquisition sessions (days) of 27 problems each. The minor variations that do appear seem to be random rather than systematic.

Practice effects.--The effects of practice on COTRAN performance are shown in Figures 5 through 9 (pp. 46-50). Each figure presents the data of one of the five COTRAN factors. Each data point is the arithmetic mean of the performance of 20 subjects on the 27 problems of a given session, or 540 observations in all.

The analyses of variance of these data resulted in statistically significant F-ratios for all measures except #9 (F = 70.52, 120.89, 18.16, 12.06, 11.76,

[1]Figure 4 and all subsequent figures have been grouped for the reader's convenience at the end of this report, pp. 45 through 64.

70.95, 105.05, 111.55, and 0.57, for measures #1 through #9, respectively; df = 7/133, $P < .001$ in each significant case). Additional Newman-Keuls analyses were computed for the data of measures #1 through #8 in order to permit identification of the session beyond which significant gains in performance no longer took place. The results of these analyses indicated that measures #4 and #5 showed no significant gains beyond session 2, measure #3 beyond session 4, and measures #1, #2, #6, #7, and #8 beyond session 6; measure #9, of course, showed no significant gain in performance throughout.

Although the greatest changes in measures #1 and #2 (Fig. 5, p. 46) and measures #6 and #7 (Fig. 8, p. 49) are the changes that occur between the first and second sessions, the changes from sessions 2 to 6 are monotonic and fairly linear; beyond session 6, performance is essentially asymptotic. A similar pattern occurs with measure #3 (Fig. 6, p. 47), except that the curve levels off earlier with no significant gains beyond session 4. There are no significant changes in measures #4 and #5 (Fig. 7, p. 48) beyond session 2, even though the improvement in performance appears to have continued through session 3. Measures #8 and #9 (Fig. 9, p. 50), which represent factor V (speed and accuracy in phase II), present dissimilar pictures of the changes in performance with continued practice. Measure #8 is patterned like measures #1 and #2 with performance increasing through session 6, and asymptotic beyond that. On the other hand, no significant over-all differences among the session means were obtained with measure #9. Since measure #9 is equivalent to the reciprocal of phase-II errors or resets in the present study, the score obtained varies as a function of the specific phase-II problem presented. That is to say, in the present case measure #9 is very nearly a random variable that depends greatly on the specific problems used; it may depend to some smaller extent on the subject's acquired skill in solving COTRAN problems.

In general, these data are interpreted as an indication that COTRAN problem-solving performance improved markedly during the first two or three sessions (54 to 81 problems); the rate of improvement beyond that point was considerably reduced. Also, the measures that represent the time aspects of the COTRAN problem-solving skill (#6 and #7) appear to require more practice for asymptotic performance to be reached than do the measures that represent the error or accuracy aspects of performance (#4 and #5). These latter measures appear to asymptote relatively quickly with almost no change after the first two or three sessions, whereas the time measures do not attain stability until session 6 and beyond.

Effects of transformation complexity.--An analysis of variance was computed for each of the nine measures of COTRAN performance using first the data of session 1 (in order to repeat previous tests for effects during the early stages of skill acquisition as reported by Alluisi and Coates, 1967, p. 20), and then the data of session 8 (in order to test for effects after asymptotic levels of performance had been obtained with all measures). Summaries of these analyses are presented in Tables 5 and 6 (pp. 20 and 21) for the data of sessions 1 and 8, respectively.

During session 1, transformation complexity apparently was not statistically significant with any of the COTRAN measures, although subject variability was, with all except measure #9. Similar results for subject variability were obtained during session 8, but here statistically significant transformation complexity effects were also obtained with measures #6 and #7. Skilled problem-solving performance, as represented by the two measures of COTRAN factor IV or time in problem solving, is apparently influenced by transformation complexity as shown in Figure 10 (p. 51) where the session-8 mean of each transformation-complexity level of these two measures is given. The time required for COTRAN problem-solving (phase-III) performance at asymptote is apparently greater for the 5-element than for either the 3- or 4-element transformations.

Table 5

Summaries of Analyses of Variance of the Nine COTRAN Measures: Data of Session 1

Measure Number (and Factor)	Source of Variation (and df)				
	Transformations (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I)[1]	0.7494	1.489	6.7432	13.401***	0.5032
2 (I)[1]	0.3406	1.222	6.1919	22.212***	0.2788
3 (II)[1]	29.2349	---	214.8392	3.181**	67.5405
4 (III)	4.6444	---	39.3255	3.426**	11.4789
5 (III)[2]	0.5007	---	11.4153	5.717***	1.9969
6 (IV)	1.3396	---	6.2058	4.338***	1.4306
7 (IV)[2]	77.5244	1.892	213.7128	5.217***	40.9651
8 (V)[1]	0.4637	---	6.0137	12.412***	0.4845
9 (V)	0.1578	---	0.2128	---	0.2910

**P < .01 ***P < .001 [1]Mean square multiplied by 10,000 [2]Mean square divided by 100

Table 6

Summaries of Analyses of Variance of the Nine COTRAN Measures: Data of Session 8

Measure Number (and Factor)	Source of Variation (and df)				
	Transformations (2)		Subjects (19)		Residual (38)
	Mean Square	F	Mean Square	F	Mean Square
1 (I)[1]	0.8777	---	31.8745	10.084***	3.1609
2 (I)[1]	0.2295	---	31.1607	16.174***	1.9266
3 (II)[2]	0.5474	---	39.5399	3.130**	12.6319
4 (III)	0.7841	---	3.2896	4.441***	0.7407
5 (III)	0.6167	---	113.9158	5.116***	22.2658
6 (IV)	3.3582	11.286***	1.1446	3.847***	0.2978
7 (IV)[3]	54.2427	12.495***	21.4233	4.935***	4.3411
8 (V)[1]	0.0924	---	32.2786	8.311***	3.8836
9 (V)	0.1010	---	0.2341	---	0.3647

**$P < .01$ ***$P < .001$ [1]Mean square multiplied by 100,000 [2]Mean square multiplied by 1,000 [3]Mean square divided by 100

Finally, these analyses were extended to discover when measures #6 and #7 became sensitive to the effects of transformation complexity. Specifically, a separate analysis of variance was computed for each of the eight sessions. The F-ratios obtained with these analyses are listed in Table 7 (p. 22). It is apparent that performance was significantly affected by transformation complexity during session 4 and beyond, with the possible exception of session 7.

The Transfer Phase

Analyses of the data of the five transfer-phase sessions were guided by the fourth general experimental question listed on page 6. Thus, the analyses dealt principally with the effects of work-load stress and various amounts of acquisition-phase practice on skilled COTRAN performance. However, since

Table 7

F-Ratios Obtained With Analyses of Variance of Measures #6 and #7: Data of Sessions 1 Through 8

Session Number	Measure #6		Measure #7	
	Transformations[1]	Subjects[2]	Transformations[1]	Subjects[2]
1	---	4.343***	1.895	5.218***
2	---	2.858**	---	3.899***
3	---	2.596**	---	3.523***
4	3.673*	3.382***	3.900*	5.696***
5	4.862*	1.523	3.960*	1.302
6	7.999**	4.883***	9.900***	4.699***
7	2.478	3.295***	2.884	3.838***
8	9.868***	5.521***	11.130***	4.566***

*$P < .05$ **$P < .01$ ***$P < .001$ [1]df = 2/38, in each case [2]df - 19/38, in each case

subjects performed concurrently both the COTRAN task and certain of the MTP tasks, it was necessary to analyze both types of performance in order to obtain as complete a picture as possible.

Effects of work load on COTRAN performance. --As discussed previously (p. 9), five different work-load conditions were produced by requiring subjects to time-share the COTRAN task with different combinations of tasks from the MTP battery; namely, with (1) the watchkeeping tasks, (2) TID, (3) MATH, (4) watchkeeping plus TID, and (5) watchkeeping plus MATH. In addition, the data of five sessions were used. These consisted of (1) session 8, the last session of the acquisition phase; (2) session 10, the first full session of the transfer phase; (3) session 11, (4) session 12, and (5) session 13, the second, third, and fourth full sessions of the transfer phase, respectively. In the case of (1) and (2), the COTRAN task was worked without the added load of the MTP tasks; the data of session 9 were not used since that session involved only familiarization training on the MTP tasks. In the case of (3), (4), and (5), the COTRAN task was performed concurrently with the MTP tasks of the given work-load condition assigned to each subject.

The data obtained with each of the nine measures of COTRAN performance are presented in Figures 11 through 15 (pp. 52-56). In order to facilitate interpretation of these figures and the others that follow, each of the five work-load conditions has been consistently represented with an identifying symbol as follows:

(1) The watchkeeping tasks, (▲).

(2) TID (○).

(3) MATH (□).

(4) Watchkeeping plus TID (●).

(5) Watchkeeping plus MATH (■).

Analyses of variance of the data of Figures 11-15 (pp. 52-56) were computed and, where appropriate, were extended through the computation of orthogonal comparisons as indicated in the summaries given in Tables 8 through 13 (pp. 25-32). That is to say, where the work-load or time-sharing conditions were statistically significant, the basic analysis of variance was extended with orthogonal comparisons as follows:

Comparison 1 (watchkeeping vs. non-watchkeeping). --Work-load condition 1 (i.e., watchkeeping tasks only) *vs.* the mean of 2, 3, 4, and 5 (i.e., TID, MATH, TID with watchkeeping, and MATH with watchkeeping).

Comparison 2 (TID vs. MATH). --The mean of work-load conditions 2 and 4 (TID, and TID with watchkeeping) *vs.* the mean of conditions 3 and 5 (MATH, and MATH with watchkeeping).

Comparison 3 (TID: alone vs. with watchkeeping). --Work-load condition 2 *vs.* 4.

Comparison 4 (MATH: alone vs. with watchkeeping). --Work-load condition 3 *vs.* 5.

Where the effects of sessions were statistically significant, the following orthogonal comparisons were computed:

Comparison 5. --The mean of sessions 8 and 10 *vs.* the mean of sessions 11, 12, and 13.

Comparison 6. --Session 8 *vs.* session 10.

Comparison 7. --Session 11 *vs.* the mean of sessions 12 and 13.

Comparison 8. --Session 12 vs. session 13.

Finally, all significant interaction effects were further analyzed by testing the between-sessions comparisons at each level of the work-load condition.

The results obtained with measures #1 and #2 are essentially identical (Fig. 11, p. 52; Table 8, p. 25). The effects of both major variables (W and S) were statistically significant, as was their interaction (W-by-S). Comparisons 2 and 3 of the extended analysis of effects of the work-load conditions were statistically significant with both measures. That is to say, the effects of the work-load conditions which included the TID task differed significantly from those which did not, and the condition of TID alone differed significantly from that of TID with the time-shared watchkeeping tasks. Comparisons 5 and 7 of the extended analysis of the sessions' effects were also statistically significant with both measure #1 and #2. Thus, the first two sessions in which the COTRAN task was performed without the MTP tasks differed significantly from the last three sessions in which it was performed with the MTP task; i. e., the addition of the work-load stress created significant decrements in COTRAN performance. Also, since session 11 differed significantly from sessions 12 and 13, it can be inferred that there was some learning of the time-sharing involved in concurrent performance of the COTRAN and MTP tasks. It is apparent that the major decrement in performance occurred during session 11, and the major gains due to practice in the time-shared activities had occurred by session 12--the first and second sessions of work-load stress, or time-shared performance, respectively. The nature of the significant W-by-S interaction will be discussed later.

The data of measure #3 are presented in Figure 12 (p. 53); the summary of an analysis of variance of these data is given in Table 9 (p. 26). Performances among the work-load conditions did not differ significantly, but there was a statistically significant effect due to sessions. The difference between the sessions without (8 and 10) and with (11, 12, and 13) concurrent MTP-task performance provided the major source of significant variation.

The data of measures #4 and #5 are presented in Figure 13 (p. 54). As indicated in Table 10 (p. 27), neither of these measures was associated with any statistically significant effect.

The data of measures #6 and #7 are shown in Figure 14 (p. 55), and summaries of the two analyses of variance of these factor-IV measures are presented in Table 11 (p. 28). The only statistically significant major effects were those due to the differences among sessions (both measures) and the W-by-S interaction (measure #7 only). The orthogonal comparisons of the measure-#6 data indicated that the major effect was due to the difference between sessions 8 and 10, the two sessions of COTRAN performance prior to time-sharing with the MTP tasks (comparison 6). For measure #7, the principal session effects were those without (sessions 8 and 10) and with (sessions 11-13) time-shared

Table 8

Summaries of Analyses of Variance of Measures #1 and #2, the Factor-I Measures

Source of Variation	df	Measure #1 Mean Square[1]	Measure #1 F	Measure #2 Mean Square[1]	Measure #2 F
Work-load Conditions (W)	4	2.6813	3.997*	2.3329	3.645*
1. Watchkeeping vs. non-watchkeeping	(1)	1.5051	2.244	1.0116	1.581
2. TID vs. MATH	(1)	1152.9360	1718.731***	1153.8005	1802.861***
3. TID: Alone vs. with watchkeeping	(1)	5.7672	8.597*	5.3107	8.298*
4. MATH: Alone vs. with watchkeeping	(1)	1.5031	2.241	1.1470	1.792
Within	15	0.6708	---	0.6400	---
Sessions (S)	4	3.2964	42.169***	2.6289	39.595***
5. S(8+10) vs. S(11+12+13)	(1)	8.7772	112.284***	6.8840	103.684***
6. S(8) vs. S(10)	(1)	0.0983	1.257	0.0536	---
7. S(11) vs. S(12+13)	(1)	0.7218	9.233**	0.6552	9.868**
8. S(12) vs. S(13)	(1)	0.0748	---	0.1665	2.507
W-by-S Interaction	16	0.2612	3.341***	0.3080	4.640*
Residual	60	0.0780	---	0.0664	---

*P<.05 **P<.01 ***P<.001 [1]Mean square multiplied by 100,000

Table 9

Summary of an Analysis of Variance of Measure #3, the Factor-II Measure

Source of Variation	*df*	Mean Square[1]	*F*
Work-load Conditions (W)	4	0.3764	---
Within	15	0.4292	---
Sessions(S)	4	0.5451	8.977***
5. S(8+10) *vs*. S(11+12+13)	(1)	1.3240	21.807***
6. S(8) *vs*. S(10)	(1)	0.2149	3.539
7. S(11) *vs*. S(12+13)	(1)	0.0869	1.431
8. S(12) *vs*. S(13)	(1)	0.0241	---
W-by-S Interaction	16	0.1309	2.156
Residual	60	0.0607	---

***P<.001 [1]Mean square multiplied by 1,000

Table 10

Summaries of Analyses of Variance of Measures #4 and #5, the Factor-III Measures

Source of Variation	df	Measure #4		Measure #5	
		Mean Square[1]	F	Mean Square	F
Work-load Conditions (W)	4	2.0354	---	0.2125	---
Within	15	7.4299	---	2.2064	---
Sessions(S)	4	2.1051	1.207	0.4809	1.892
W-by-S Interaction	16	1.4814	---	0.2692	1.059
Residual	60	1.7446	---	0.2541	---

[1]Mean squares multiplied by 100

Table 11

Summaries of Analyses of Variance of
Measure #6 and #7, the Factor-IV Measures

Source of Variation	df	Measure #6 Mean Square[1]	Measure #6 F	Measure #7 Mean Square[2]	Measure #7 F
Work-load Conditions (W)	4	3.9743	---	1.8606	1.652
Within	15	5.0410	---	1.1266	---
Sessions (S)	4	2.2564	2.698*	1.3912	7.729***
5. S(8+10) vs. S(11+12+13)	(1)	3.0195	3.610	2.9473	16.373***
6. S(8) vs. S(10)	(1)	4.0772	4.875*	0.7697	4.276*
7. S(11) vs. S(12+13)	(1)	0.5589	---	0.5249	2.916
8. S(12) vs. S(13)	(1)	0.1613	---	0.1439	---
W-by-S Interaction	16	1.1513	1.377	0.4230	2.350**
Residual	60	0.8364	---	0.1800	---

*$P < .05$ **$P < .01$ ***$P < .001$ [1]Mean square multiplied by 100 [2]Mean square divided by 100

Table 12

Summaries of Analyses of Variance of Measure #8 and #9, the Factor-V Measures

Source of Variation	df	Measure #8 Mean Square[1]	Measure #8 F	Measure #9 Mean Square[2]	Measure #9 F
Work-load Conditions (W)	4	0.2107	3.314*	0.3791	2.251
1. Watchkeeping *vs.* non-watchkeeping	(1)	0.0948	1.492	N/A	N/A
2. TID *vs.* MATH	(1)	115.4569	1816.049***	N/A	N/A
3. TID: Alone *vs.* with watchkeeping	(1)	0.4869	7.658*	N/A	N/A
4. MATH: Alone *vs.* with watchkeeping	(1)	0.0835	1.314	N/A	N/A
Within	15	0.0636	---	0.1684	---
Sessions (S)	4	0.2234	25.679***	0.0848	---
5. S(8+10) *vs.* S(11+12+13)	(1)	0.5683	65.320***	N/A	N/A
6. S(8) *vs.* S(10)	(1)	0.0089	1.028	N/A	N/A
7. S(11) *vs.* S(12+13)	(1)	0.0592	6.808*	N/A	N/A
8. S(12) *vs.* S(13)	(1)	0.0296	3.402	N/A	N/A
W-by-S Interaction	16	0.0374	4.299***	0.0971	---
Residual	60	0.0087	---	0.0995	---

*P <.05 ***P <.001 N/A -- Not Applicable [1]Mean square multiplied by 10,000 [2]Mean square multiplied by 100 performance of the MTP tasks (comparison 5), and the two sessions without time-sharing (session 8 vs. 10; comparison 6). The significant W-by-S interaction obtained with measure #7 will be discussed later.

Only with these two measures, #6 and #7, were significant differences found between sessions 8 and 10; thus, the sole effect of the month's delay (between sessions 8 and 10, the last of the acquisition trials and the first full "retraining" session) was apparently an increase in the time required to complete the problem-solving third phase of the COTRAN task.

The data of measures #8 and #9 are presented in Figure 15 (p. 56); results of the extended analyses of variance of these measures are summarized in Table 12 (p. 29). The results obtained with measure #8 are almost identical to those obtained with measures #1 and #2. That is to say, the effects of the work-load conditions were statistically significant, with the major effects' being attributable to the differences represented in comparisons 2 and 3. The effects due to sessions were also statistically significant, with major sources of variations represented by differences in comparisons 5 and 6. Finally, the W-by-S interaction was statistically significant with the data of measure #8. On the other hand, the data of measure #9, like those of measures #4 and #5, resulted in the identification of no significant sources of variation among the major variables. All three of these measures (#4, #5, and #9) are based on error or reset ratios: measure #4 is the ratio of errors in phase III to the mean number of errors in phases I and II, measure #5 is the reciprocal of errors in phase III, and measure #9 is the reciprocal of errors in phase II. Thus, it appears that the increased work loads produced by the time-shared MTP tasks did not affect the number of errors made in phases II or III. The work-load stress did affect each of the other measures to some extent.

The pattern that seems to emerge from these results may be summarized as follows: First, statistically significant differences among the work-load conditions were obtained with the "time" measures of phases I and II (i. e., measures #1, #2, and #8). In each case, further tests with orthogonal comparisons indicated that the mean COTRAN performance under the two TID conditions ("alone" and "with watchkeeping") differed from that under the two corresponding MATH conditions. Also, the work-load condition of TID alone differed significantly from that of TID with the time-shared watchkeeping tasks.

Secondly, the "error" measures of phases II and III (i. e., measures #4, #5, and #9) were not affected significantly by either of the major variables employed in this study. The work-load stress apparently had no effect on that aspect of COTRAN performance which is represented by these "error" measures.

Thirdly, COTRAN performance measured with six of the nine measures (all except the three "error" measures discussed in the second point) changed significantly over the course of the five sessions. The addition of the work-load

stress during sessions 11, 12, and 13 is associated with statistically significant decrements in COTRAN performance. The most general results of the orthogonal comparisons of these data were the statistically significant differences between the mean of sessions 8 and 10 versus that of sessions 11, 12, and 13 (comparison 5) which occurred with measures #1, #2, #3, #7, and #8. This is interpreted as an indication that the COTRAN task is sensitive to the effects of work-load stress, at least with certain of the measures of performance employed.

This conclusion is supported further by the results of additional orthogonal comparisons that are summarized in Table 13 (p. 32). Reported in the table are the results of separate analyses: (1) of the data of each of the five measures associated with statistically significant W-by-S interactions (cf. Tables 8-12), (2) at each level of the five work-load conditions, (3) computed over the "sessions" dimension with the four orthogonal comparisons defined previously (p. 23).

The difference between the mean of the two sessions preceding the introduction of the MTP tasks (sessions 8 and 10) and that of the three sessions under any of the five work-load conditions (sessions 11, 12, and 13) was statistically significant in each case (comparison 5). Of the six remaining statistically significant differences, five were obtained under the fourth and fifth work-load conditions with comparison 7 (session 11 <u>vs.</u> the mean of sessions 12 and 13). This indicates, of course, that practice effects soon begin to correct the detrimental effects of the heavier work-load conditions.

<u>Performance of the MTP tasks.</u> --Nine criteria were used to represent the performances of MTP tasks. These measures (and the tasks they represent) are identified below:[2]

1. Mean normalized speed (green warning lights).

2. Mean normalized speed (red warning lights).

3. Mean normalized speed (blinking lights).

4. Percentage of signals detected (probability monitoring).

5. Mean detection speed (probability monitoring).

6. Percentage correct of problems attempted (TID).

7. Percentage of problems attempted (TID).

[2]The MTP tasks were described briefly in the Methods Section (pp. 7-13); full descriptions of the tasks and the measures of performance employed with them are given elsewhere (Adams & Chiles, 1960; 1961; Alluisi et al., 1962; 1963; 1964; 1967).

Table 13

F-Ratios Obtained With Orthogonal Comparisons of the Data of Each of Five Work-Load Conditions

Work-load Condition and Source of Variation 1	Measure				
	#1	#2	#3	#7	#8
Work-load Condition 1: (Watchkeeping only)					
5. S(8+10) vs. S(11+12+13)	1030.220***	1412.650***	497.598***	92.513***	1701.178***
6. S(8) vs. S(10)	---	---	6.075*	---	---
7. S(11) vs. S(12+13)	1.185	1.031	---	---	---
8. S(12) vs. S(13)	---	---	---	---	---
Work-load Condition 2: (TID)					
5. S(8+10) vs. S(11+12+13)	1794.126***	3311.985***	487.970***	35.048***	2613.930***
6. S(8) vs. S(10)	---	1.352	---	1.661	1.418
7. S(11) vs. S(12+13)	---	---	---	---	---
8. S(12) vs. S(13)	1.413	2.599	---	1.010	2.027
Work-load Condition 3: (MATH)					
5. S(8+10) vs. S(11+12+13)	1040.715***	1108.030***	644.740***	8.821*	1022.448***
6. S(8) vs. S(10)	---	---	---	---	---
7. S(11) vs. S(12+13)	1.386	---	4.498	---	---
8. S(12) vs. S(13)	---	---	2.256	---	---
Work-load Condition 4: (Watchkeeping plus TID)					
5. S(8+10) vs. S(11+12+13)	1083.702***	844.749***	310.159***	26.914***	512.921***
6. S(8) vs. S(10)	1.534	---	---	2.729	---
7. S(11) vs. S(12+13)	4.082	7.347*	---	4.812*	8.050*
8. S(12) vs. S(13)	---	1.459	---	2.615	2.125
Work-load Condition 5: (Watchkeeping plus MATH)					
5. S(8+10) vs. S(11+12+13)	5042.226***	29801.554***	863.678***	168.645***	5047.795***
6. S(8) vs. S(10)	---	---	---	2.152	---
7. S(11) vs. S(12+13)	7.984*	18.638***	---	---	---
8. S(12) vs. S(13)	1.007	2.350	---	---	---

*$P < .05$ ***$P < .001$ 1 df = 1/12, in each case

8. **Percentage correct of problems attempted (MATH).**

9. Percentage of problems attempted (MATH).

The data obtained with these measures are presented in Figures 16 through 22 (pp. 57-63). In each figure, data are presented from the work-load conditions indicated; note also that the percentages correct of both the TID and the MATH problems attempted are presented in Figure 21 (p. 62). Likewise, the percentages attempted of both the TID and the MATH problems presented are given in Figure 22 (p. 63). Each of the other measures is presented separately. The symbols used to identify the work-load conditions are those previously described on page 23.

Analyses of variance similar in design to those reported in the preceding section were used with these data; the work-load conditions and the performance sessions constituted the two dimensions of each analysis. There were always four levels of the session dimension, these being sessions 9, 11, 12, and 13 (the data of session 10 included no performance with the MTP tasks). Where appropriate, orthogonal comparisons were made to compare (1) session 9 with the mean of sessions 11, 12, and 13, (2) session 11 with the mean of session 12 and 13, and (3) session 12 with session 13. The first comparison was of particular interest since its significance would imply that performance on the MTP tasks was different with (sessions 11, 12, and 13) and without (session 9) concurrent performance of the COTRAN task.

The number of work-load levels varied as a function of the measure being analyzed; the watchkeeping measures had three levels (alone, with TID, and with MATH), whereas the non-watchkeeping measures had four levels (TID, MATH, TID with watchkeeping, and MATH with watchkeeping).

Neither of the two major variables produced significant effects with most of the MTP measures. In fact, statistically significant differences were obtained with only two measures; namely, (1) percentage of probability signals detected, and (2) percentage of TID and MATH problems attempted. Summaries of the analyses of these two measures are presented in Table 14 (p. 34).

In terms of the percentage of probability-monitoring signals detected (Fig. 19, p. 60), there were statistically significant effects due to sessions, and as indicated by the orthogonal comparisons, the major source of the session differences was the difference between session 9 and the mean of sessions 11, 12, and 13 (comparison 1). In terms of the percentage of TID and MATH problems attempted (Fig. 22, p. 63), both major variables were statistically significant, as was their interaction. The orthogonal comparisons indicated that comparison 1 was again statistically significant, as it was also within the MATH and the watchkeeping-with-MATH conditions (F = 37.673 and 60.116, respectively; df = 1/9, $P < .001$ in each case). That is to say, the percentage of MATH problems

Table 14

Summaries of Analyses of Variance of
(1) Percentage of Probability-Monitoring Signals Detected, and
(2) Percentage of TID and MATH Problems Attempted

Source of Variation	df	Probability Monitoring		TID and MATH Attempted	
		Mean Square[1]	F	Mean Square[2]	F
Work-load Conditions (W)	3	2.5997	1.264	52.6268	7.524**
Within	12	2.0575	---	6.9942	---
Sessions (S)	3	1.1032	3.481*	10.2129	17.781***
1. S(9) vs. S(11+12+13)	(1)	2.7591	8.706**	30.2617	52.686***
2. S(11) vs. S(12+13)	(1)	0.0660	---	0.3715	---
3. S(12) vs. S(13)	(1)	0.4847	1.529	0.0046	---
W-by-S Interaction	9	0.2382	---	2.2610	3.936**
Residual	36	0.3169	---	0.5744	---

*P < .05 **P < .01 ***P< .001 [1]Mean square divided by 1,000
[2]Mean square divided by 100

attempted was lowered when the subject had to solve COTRAN simultaneously with MATH during sessions 11, 12, and 13.

Thus, it appears that MATH and watchkeeping-plus-MATH were the only work-load conditions under which MTP performance could not be maintained with concurrent work on the COTRAN task. In both cases, subjects were not able to respond to as many MATH problems while time-sharing COTRAN performances; the percentage correct of the MATH problems attempted, however, was not adversely affected by concurrent COTRAN performance.

Effects of amount of COTRAN practice. --The scores obtained with each of the nine measures of COTRAN performance during the second (without MTP tasks), third, fourth, and fifth (each with TID) transfer sessions, by each of the three groups that had different amounts of initial acquisition-phase practice

(4, 8, or 12 sessions) are given in Table 15 (p. 36). Summaries of the analyses of variance of these data, where significant results were obtained, are given in Table 16 (p. 37).

The amount of initial acquisition-phase practice produced significant effects in none of the cases. Thus, the three levels of practice employed in this study failed to yield differential COTRAN performance during the transfer phase. The effects of sessions, however, were statistically significant with COTRAN measures #1, #2, #7, and #8, and the results of orthogonal comparisons imply that the major differences are those of the first versus the last three transfer sessions (comparison 1 in Table 16, p. 37). Thus, COTRAN performance during the first transfer session (without any concurrent MTP task) was better than the average performance during the subsequent three sessions (with the TID task). Comparison 2 in the case of Measure #7 was also statistically significant; i.e., with this measure, COTRAN performance was poorer during session 3 than sessions 4 and 5 (first versus final two sessions with time-sharing). These results are essentially identical to those found previously in the analyses of work-load effects, except that they are generalized here to the three levels of acquisition-phase practice.

Discussion

The present study was conducted as part of a program of research that is more generally concerned with the assessment of human performance in complex man-machine systems (cf. Alluisi, 1967). The specific goal of this research has been the development of a task that could be employed to obtain performance measures of man's intellectual functioning, or nonverbal mediation, in problem-solving behavior. The task is to be incorporated into a multiple-task performance (MTP) battery with which a synthetic-work situation can be created.

The design and construction of a code-transformation (COTRAN) task that apparently provides suitable measures of problem-solving behavior, and the investigation of two of its parameteric dimensions have been reported previously (Alluisi & Coates, 1967). The COTRAN task appears to provide a method for measuring certain characteristics of intellectual functioning; namely, the speed and accuracy of the nonverbal-mediational aspects of problem-solving behavior.

The previous studies had left unanswered certain questions related to the task's incorporation into the MTP battery. These questions dealt mainly with certain aspects of the acquisition of the problem-solving skill and of the nature of skilled COTRAN performances. The present study was conducted in order to obtain data regarding the effects on COTRAN performance both of practice and of the work loads imposed by different combinations of time-shared MTP tasks. Four general experimental questions were listed at the end of the Introduction (p. 6), and these questions have been used to structure the discussion that follows.

Table 15

Mean Values of the Nine COTRAN Measures During Transfer Sessions 2, 3, 4, and 5, for Each of Three Groups With Different Amounts of Practice

Measure	Group and Number of Practice Sessions	Transfer Session 2	3	4	5
#1	4	0.0249	0.0233	0.0228	0.0234
	8	0.0259	0.0234	0.0233	0.0240
	12	0.0245	0.0220	0.0218	0.0228
#2	4	0.0250	0.0230	0.0232	0.0233
	8	0.0258	0.0237	0.0234	0.0241
	12	0.0246	0.0219	0.0220	0.0230
#3	4	0.1297	0.1236	0.1237	0.1240
	8	0.1312	0.1265	0.1319	0.1270
	12	0.1282	0.1300	0.1197	0.1273
#4	4	0.2710	0.3062	0.2911	0.2688
	8	0.1703	0.1732	0.1590	0.2664
	12	0.1721	0.1551	0.2669	0.0844
#5	4	1.2037	1.6111	1.5185	1.3525
	8	0.8704	0.9815	0.9907	1.3704
	12	0.7593	0.9074	1.2963	0.3981
#6	4	0.6174	0.6683	0.6435	0.6645
	8	0.5677	0.6564	0.6348	0.5884
	12	0.5129	0.6301	0.5257	0.5117
#7	4	24.9574	29.7188	28.4046	29.2463
	8	22.1194	28.2954	27.6815	25.0426
	12	21.8509	30.4370	24.9139	22.7806
#8	4	0.2510	0.0228	0.0235	0.0232
	8	0.0256	0.0241	0.0235	0.0241
	12	0.0247	0.0218	0.0222	0.0231
#9	4	0.2620	0.2430	0.2540	0.2537
	8	0.2417	0.2355	0.2044	0.2213
	12	0.2319	0.2158	0.2232	0.2210

Table 16

Summaries of Analyses of Variance of Measures #1, #2, #7, and #8

Source of Variation	df	#1 F (or MS[1])	#2 F (or MS[1])	#7 F (or MS[2])	#8 F (or MS[1])
Practice (P)	2	---	---	---	---
Within	9	(0.1267)	(0.1405)	(127.0587)	(0.1575)
Transfer Sessions (TS)	3	11.607***	14.079***	5.140**	12.074***
1. TS(1) *vs.* TS(2+3+4)	(1)	31.834***	39.560***	10.227**	34.189***
2. TS(2) *vs.* TS(3+4)	(1)	---	---	4.593*	1.171
3. TS(3) *vs.* TS(4)	(1)	2.910	2.143	---	---
P-by-TS Interaction	6	---	---	---	---
Residual	27	(0.0124)	(0.0096)	(17.1543)	(0.0106)

*$P < .05$ **$P < .01$ ***$P < .001$ [1]Mean square (MS) multiplied by 10,000
[2]Mean square (MS) multiplied by 100

Factor Structure of the COTRAN Task

The stability of the COTRAN factor structure was measured by having 20 subjects solve 27 COTRAN problems on each of eight successive days. A factor analysis of the session-1 data permitted a comparison to be made of the factorial structure obtained in the present study with those of two prior experiments (Alluisi & Coates, 1967). Then, a factor analysis of the session-8 data permitted a comparison to be made of the structure before and after practice. Each of these analyses resulted in the identification of the same five factors: (I) *general accuracy*, (II) *general response rate* (both of these factors relate to performances in phases I and II of the COTRAN problems), (III) *errors in problem solving*, (IV) *time in problem solving* (both of which relate to performance in phase III, the problem-solving phase of the COTRAN problems), and (V) *speed and accuracy in phase II*. Interpretations of these factors have been presented elsewhere (Alluisi & Coates, 1967, pp. 31-32) and will not be repeated here.

The important thing to note is the consistency with which Varimax rotation of principle-axis factorial solutions produce the identical five COTRAN factors across different experimental (memory-aid) conditions (Alluisi & Coates, 1967), different subjects, experiments, and times (Table 4, p. 18), and different amounts of practice (Fig. 4, p. 45). Stability such as this is a desirable characteristic of any task that is to be used in experimental settings to measure any aspect of man's problem-solving performance. The COTRAN task seems to score well in this regard.

Effects of Practice on COTRAN Performance

The acquisition of skill is generally characterized not only by an improvement in the efficiency of making certain responses, but also by the learning of new responses as old ones are eliminated during practice. Thus, it might be expected that qualitative as well as quantitative differences should have differentiated skilled and unskilled COTRAN performances. Such qualitative differences should have been evidenced in the present case as changes in the relative contributions of the five COTRAN factors to the total explained variance over the practice sessions.

As was indicated by the data of Figure 4 (p. 45)., however, the percentage of total variance accounted for by the several factors remained essentially constant from session 1 through session 8. This differs from the results obtained in studies of psychomotor skills (e.g., Fleishman & Hempel, 1956), wherein it has been found generally that (a) the specific contributions of different combinations of abilities change as practice continues, (b) these changes are progressive and systematic, but eventually stabilize, (c) the contribution of "non-motor" abilities, which may play a role early in learning (e.g., verbal and spatial), decreases systematically with practice relative to "motor abilities", and (d) factors specific to the task itself increase in importance as practice is continued (Fleishman, 1966, p. 159). Even though these conclusions relate to psychomotor "ability" factors, it is not unreasonable to expect them to apply to the task-specific COTRAN factors (especially, factors III and IV). Yet, essentially no change was observed in the relative contribution of any of the five COTRAN factors. Of course, it may have been that such changes did take place, but were completed by the end of the first session of practice (the first 27 COTRAN problems).

In order to test this hypothesis, a principle-axis factor analysis with Varimax rotation was computed for each of the nine blocks of three problems that were solved during session 1. The percentage of total variance accounted for by each of the five COTRAN factors is presented in Figure 23 (p. 64) for each of the nine blocks of problems. Although the variability here is greater than in the data of Figure 4 (p. 45), the results are essentially the same; namely, there is no consistent change with practice.

A parsimonious interpretation of these findings is that "intellectual" and "psychomotor" skills differ in these regards. The COTRAN task is certainly more intellectual in nature than the psychomotor tasks to which Fleishman's generalizations applied! This hypothesis might prove to be interesting should it be validated with further testing.

The quantitative differences between the performances of session 1 and session 8 were shown in the data of Figures 5 through 9 (pp. 46 to 50). Two important results should be mentioned concerning these data. First, none of the nine measures produced a significant change beyond session 6, so that performance during sessions 6, 7, and 8 should be considered essentially stable and asymptotic. Secondly, those measures that are based on errors or error-ratios reached asymptote sooner than those based on time or time-ratios. Measures #4 and #5 (which represent errors in problem solving) appeared to reach asymptote during sessions 2 or 3, with no significant changes thereafter. Measure #9 (the reciprocal of errors in phase II) showed no significant changes among the eight sessions. On the other hand, measure #3 (which represents the ratio of errors to time in phases I and II) reached asymptote at session 4, and each of the purely time-based measures (#1, #2, #6, and #8) reached asymptote at session 6. Thus, the error-based measures generally reached asymptote earlier in practice than the time-based measures.

In summary, it may be concluded that there are three principal effects of practice on COTRAN performance: (1) the problem-solving skill is clearly improved with practice, (2) asymptotic levels of COTRAN performance are reached within 8 sessions of practice (as were employed in the acquisition-phase of this experiment), and (3) asymptotic levels are indicated to occur earlier with the error-based measures than with the time-based measures. These results demonstrate the importance of understanding both the nature of the measures of performance employed, and the effects of practice as measured with each such criterion. Without this knowledge, only gratuitous conclusions can be reached with regard to effects of other variables on skilled performance.

Transformation Complexity

The effects of transformation complexity on COTRAN performance were not statistically significant during session 1. This result replicates that of a previous study (Alluisi & Coates, 1967) and confirms the conclusion that unskilled COTRAN performance is unaffected by this variable. On the other hand, the analysis of the session-8 data indicated that skilled performance, as represented by measures #6 and #7, was significantly affected by transformation complexity; the performance obtained with 5-element transformations was poorer than with 3- and 4-element transformations (cf. Fig. 10, p. 51).

The data of measures #6 and #7, when further analyzed for each of the eight acquisition-phase sessions, indicated that performance was similarly and significantly affected by transformation complexity during and beyond session 4 (the data of session 7 approached, but did not reach statistical significance). The speed of problem solving in COTRAN performance (factor IV) is sensitive to at least two levels of transformation complexity after three sessions of practice (81 problems). In short, whereas transformation complexity has had no effect on COTRAN performance here or in prior studies with pre-asymptotic levels of skill, it does have a measurable effect on the speed of problem solving (factor IV) with skilled post-acquisition performance.

Effects of Work-load Stress

One of the major goals of the present study was the measurement of the effects of work-load stress on skilled COTRAN performance. This was accomplished by having subjects solve COTRAN problems concurrently with certain of the tasks from the MTP battery. It was expected that the different combinations of MTP tasks would represent different levels of work-load stress.

The analyses of the transfer-phase data indicated that each of the five work-load conditions was associated with a statistically significant initial decrement in COTRAN performance. Thus, even under the relatively "low-stress" condition (when only the watchkeeping tasks were added), the load was sufficient to disrupt COTRAN performance (see Table 12, p. 29). Comparisons of the different conditions, however, indicated that all except one of the five work loads produced essentially the same degree of disturbance to the performance of the COTRAN task; the time-sharing of both the target-identification (TID) and the watchkeeping tasks with the COTRAN task was especially detrimental to performance (see Fig. 11, p. 52). It appears, therefore, either that the COTRAN task is relatively insensitive to as many as five different levels of work-load stress, or that the five combinations of MTP tasks failed to present more than two levels with the greater work-load's occurring under the condition of TID with watchkeeping.

In establishing the five work-load conditions for this study, the expectation was that the use of the five combinations of MTP tasks would produce at least three different work loads (watchkeeping, TID or MATH, and watchkeeping plus TID or plus MATH). In fact, the MATH task has generally been considered the single most-difficult task in the MTP battery, at least in terms of its demands on channel capacity while being performed. The present data seem to provide evidence that TID is more difficult than MATH! Some further interpretation is necessary.

It should be noted that the COTRAN measures with which the significant differences were obtained were all time-based measures (#1, #2, and #8); none was an error-based measure. This suggests that TID with watchkeeping must have been time-shared with the COTRAN task differently than the tasks in the other four work-load conditions.

This suggestion is supported by the findings evidenced in certain of the MTP data. Specifically, the data of Figure 22 (p. 63) indicate that the percentage of TID problems attempted with concurrent performance of the COTRAN task was between about 80% (for TID with watchkeeping) and 90% (for TID without watchkeeping). On the other hand, the percentage of MATH problems attempted with concurrent performance of the COTRAN task was between about 45% (for MATH with watchkeeping) and 55% (for MATH without watchkeeping). The COTRAN task, it will be recalled, was most adversely affected under the first of these four conditions (i.e., under the TID-with-watchkeeping condition) on measures #1 and #2 (Fig. 11, p. 52) and #8 (Fig. 15, p. 56).

Thus, it is suggested that in time-sharing the COTRAN task under the two TID conditions, the subjects generally tended to postpone their responses to the self-paced COTRAN task until they had completed the force-paced TID task. The subjects who time-shared COTRAN under the two MATH conditions, however, apparently adopted a different strategy: they seem to have responded first to the easier COTRAN problems, then to have attempted to solve the MATH problems only when sufficient time remained during the 20-sec. period each problem was presented.

The use of different response strategies when time-sharing tasks under conditions of work-load stress makes more difficult the interpretation of the results of such stresses. For example, had the COTRAN data alone been analyzed, it would have been concluded that the work-load condition of time-shared COTRAN, TID, and watchkeeping tasks was obviously the only stressful condition. Since the MTP data have also been analyzed, however, it is apparent that the two conditions which involved the time-sharing of the MATH task were also stressful. It can be concluded that the time-sharing of the COTRAN task with either the watchkeeping tasks or the TID task alone does not create an operator over-load or work-load-stress condition; the time-sharing of COTRAN with MATH or with either MATH or TID and the watchkeeping tasks does represent an operator-overload or work-load-stress condition. The effects of the stress, however, may be evidenced in either the COTRAN or the MTP performances, depending on the response strategies adopted by the operators.

Practice and Transfer Effects

The final question of interest is concerned with the effects of the amount of acquisition-phase practice on the transfer of COTRAN performance to the condition of work-load stress. Neither the COTRAN nor the MTP measures showed any differential effects of the three levels of practice employed (4, 8, or 12 sessions). This result indirectly supports an earlier conclusion regarding COTRAN problem-solving behavior; namely, that performance as measured with the problem-solving measures reached asymptotic levels in four to six sessions. The performance of each of the three groups had very nearly reached asymptote at the same level by session four, so that the performance of the two groups with eight and twelve sessions did not change significantly with the additional practice.

Conclusions

The data of the present study appear to support the following conclusions: (1) the level of the COTRAN problem-solving skill increases as a function of practice to four or six sessions (108 to 162 problems); (2) asymptotic levels of performance are indicated with error-based measures sooner than with the time-based measures of COTRAN performance; (3) the speed of problem solving is sensitive to at least two levels of transformation complexity with skilled (post-acquisition) performance; (4) skilled COTRAN performance is sensitive to at least two or three levels of work-load stress; (5) operators may tend to adopt different strategies in time-sharing other tasks with the COTRAN problem-solving task; and (6) the factorial structure of the COTRAN task appears to remain constant over conditions involving different experimental variables, different subjects, and different amounts of practice or levels of skill acquisition up to eight sessions of practice (216 problems).

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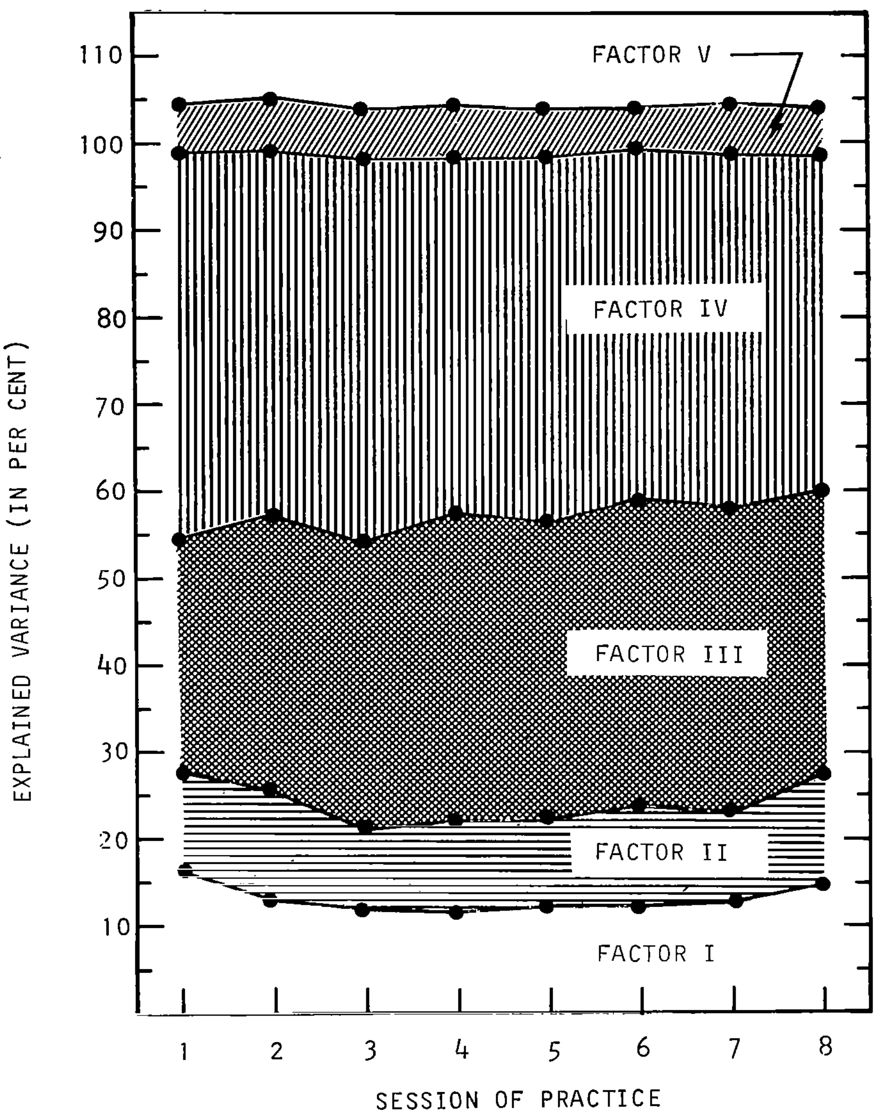

Figure 4. --Percentage of total variance explained by each of five COTRAN factors during each of eight sessions (successive days) of practice (27 COTRAN problems solved by each of 20 subjects during each session).

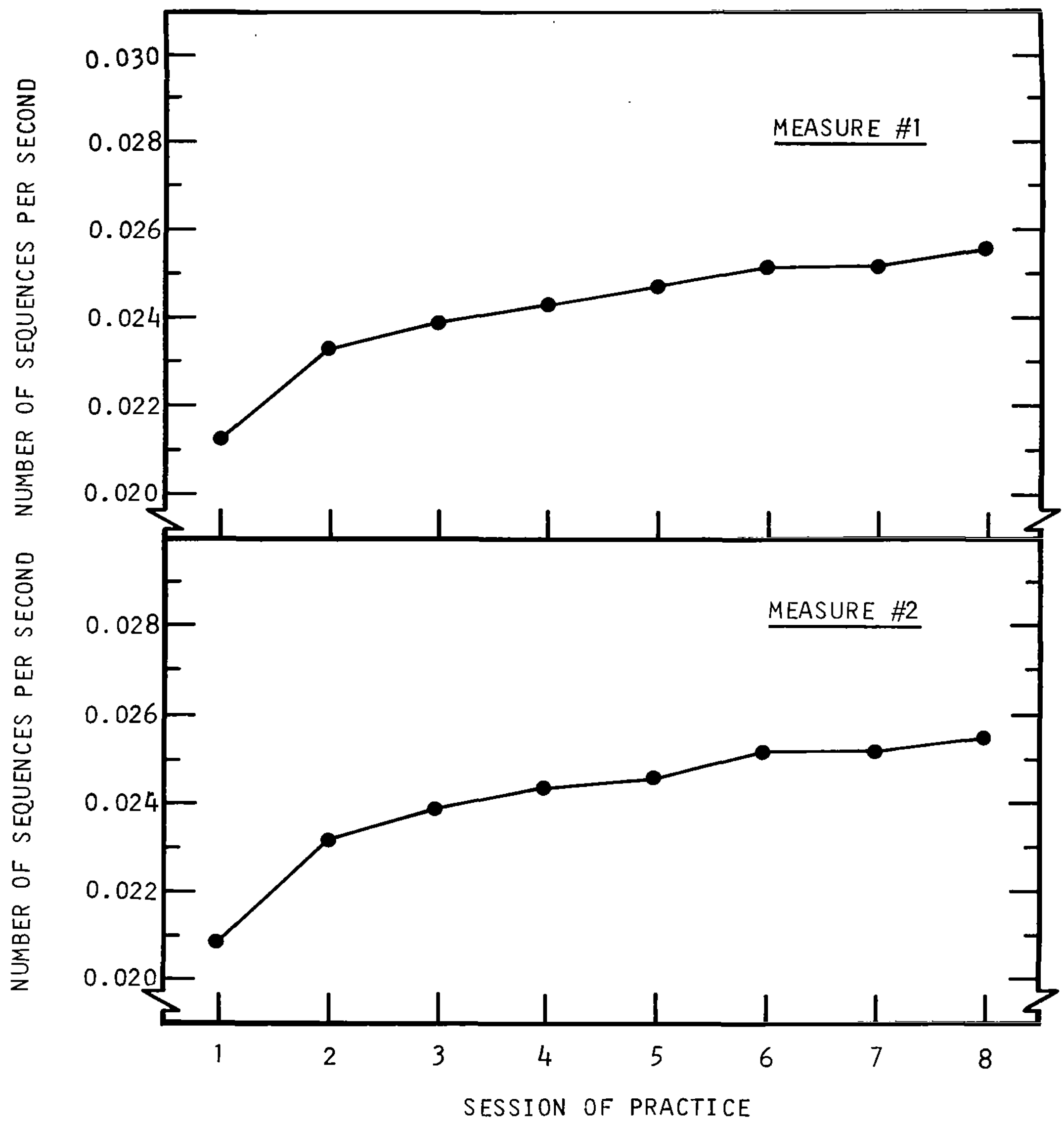

Figure 5. --Mean number of phase-I sequences per second (measure #1), and mean number of combined phase-I and phase-II sequences per second (measure #2), as functions of practice. These two measures represent factor I: general accuracy.

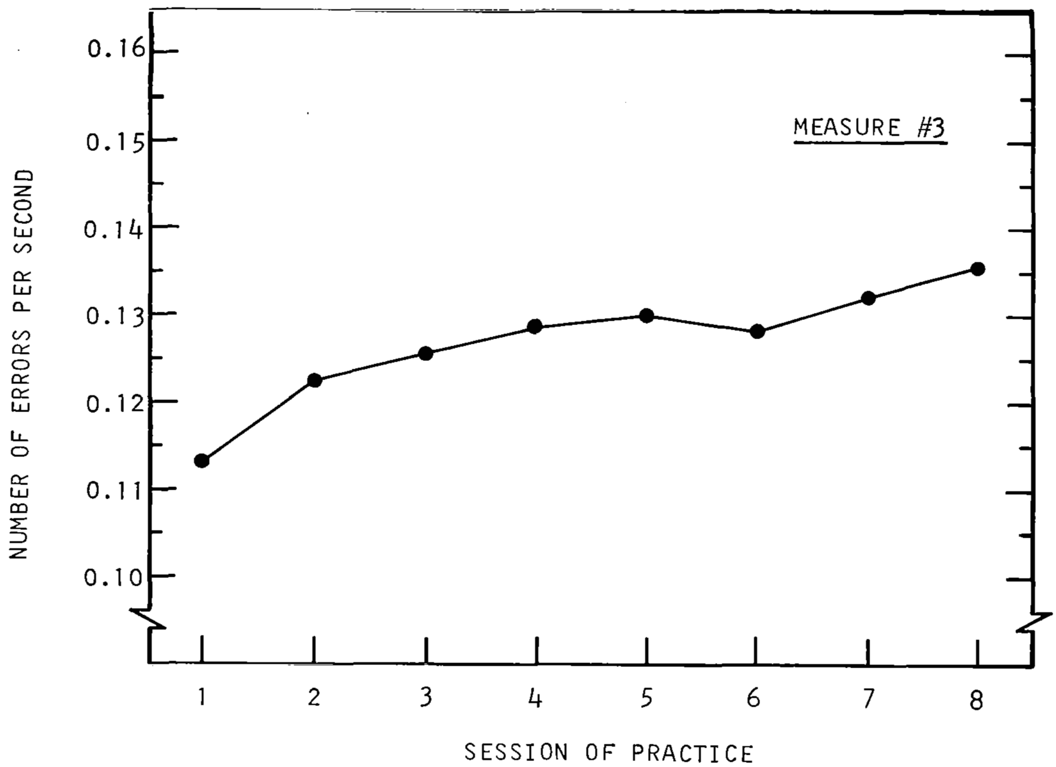

Figure 6. --Mean number of combined phase-I and phase-II errors per second (measure #3) as a function of practice. This measure represents factor II: general response rate.

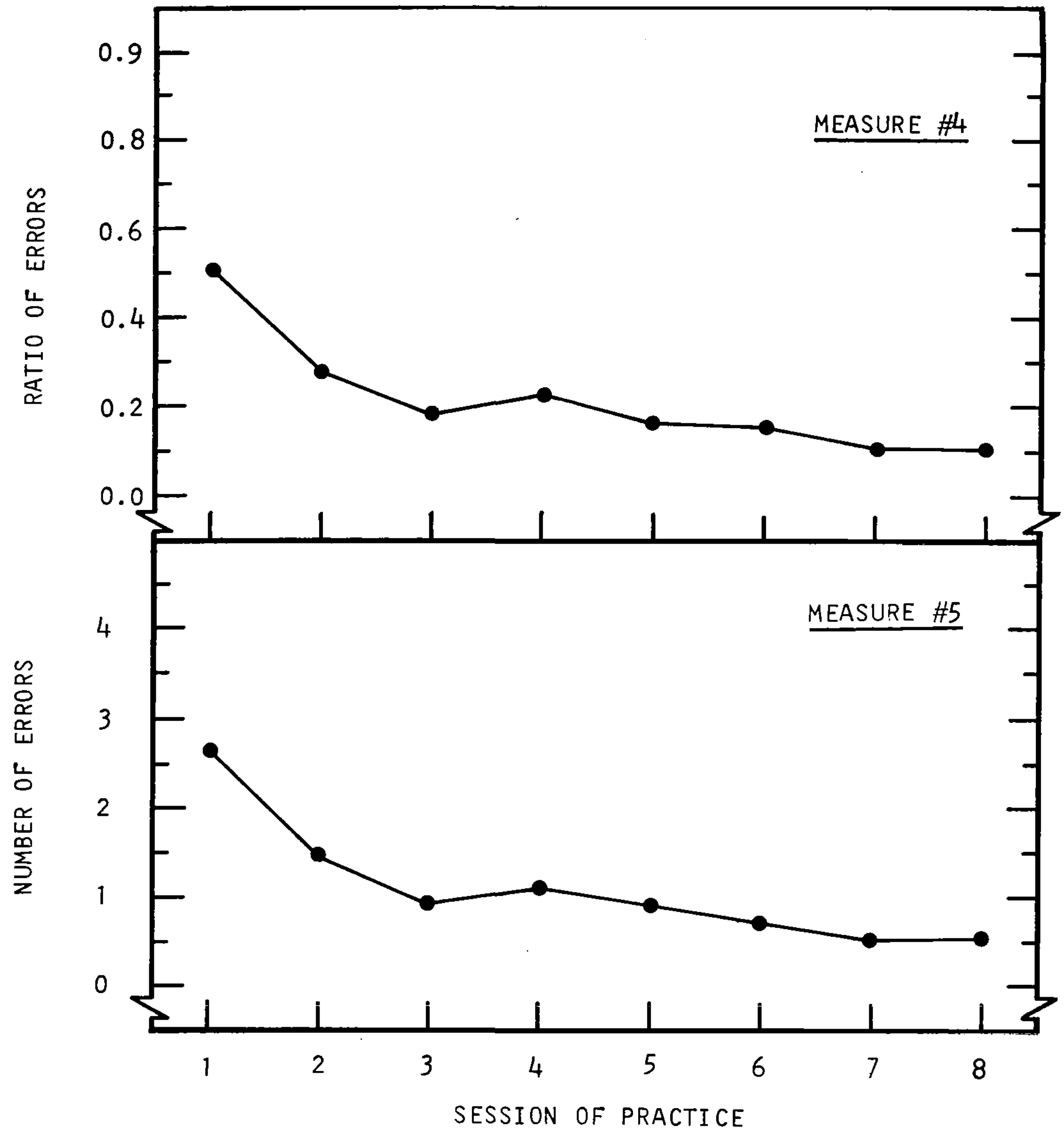

Figure 7. --Mean ratio of phase-III errors to average phase-I and phase-II errors (measure #4), and mean number of phase-III errors per sequence (measure #5), as functions of practice. These measures represent factor III: <u>errors</u> <u>in</u> <u>problem</u> <u>solving</u>.

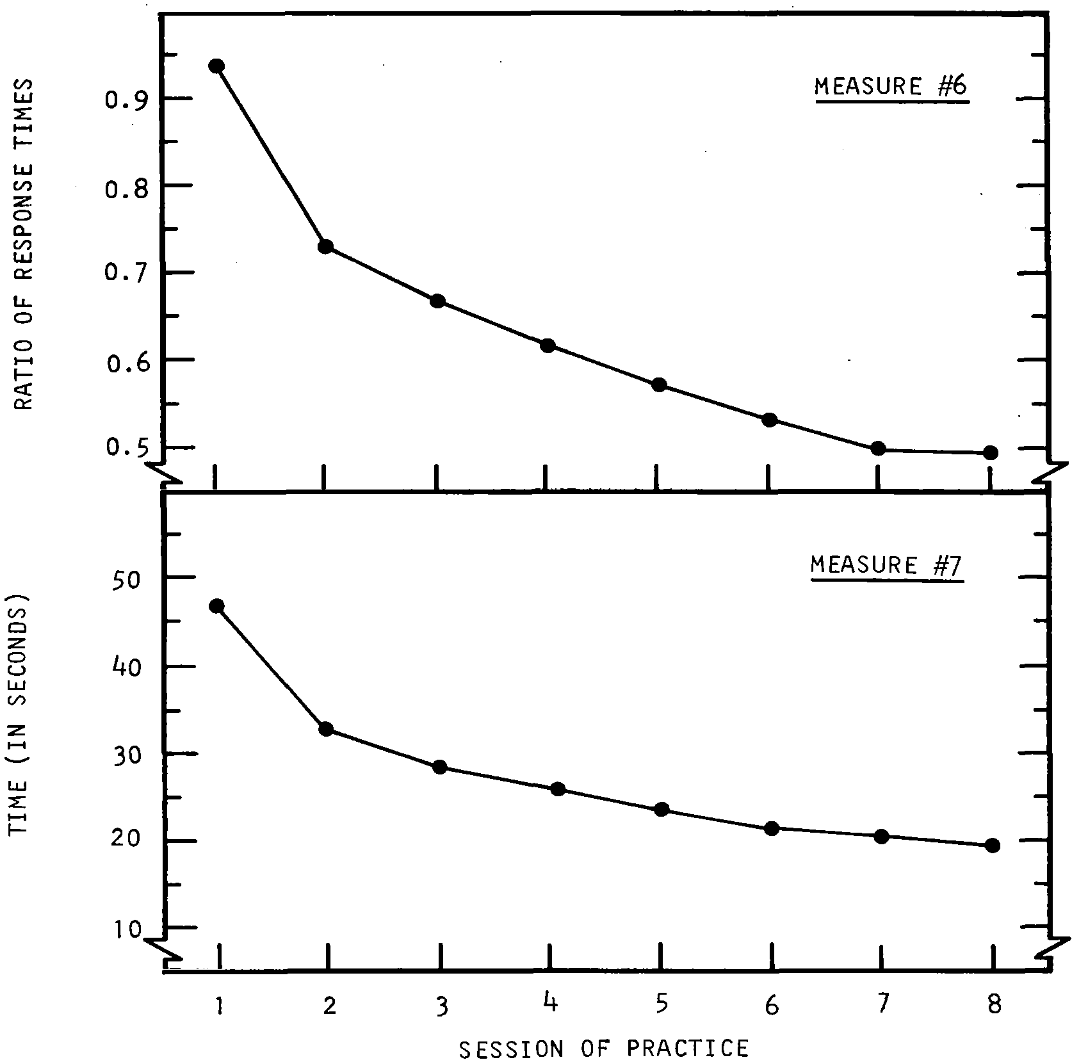

Figure 8.--Mean ratio of phase-III time to average phase-I and phase-II time (measure #6), and mean time per phase-III sequence (measure #7), as functions of practice. These measures represent factor IV: time in problem solving.

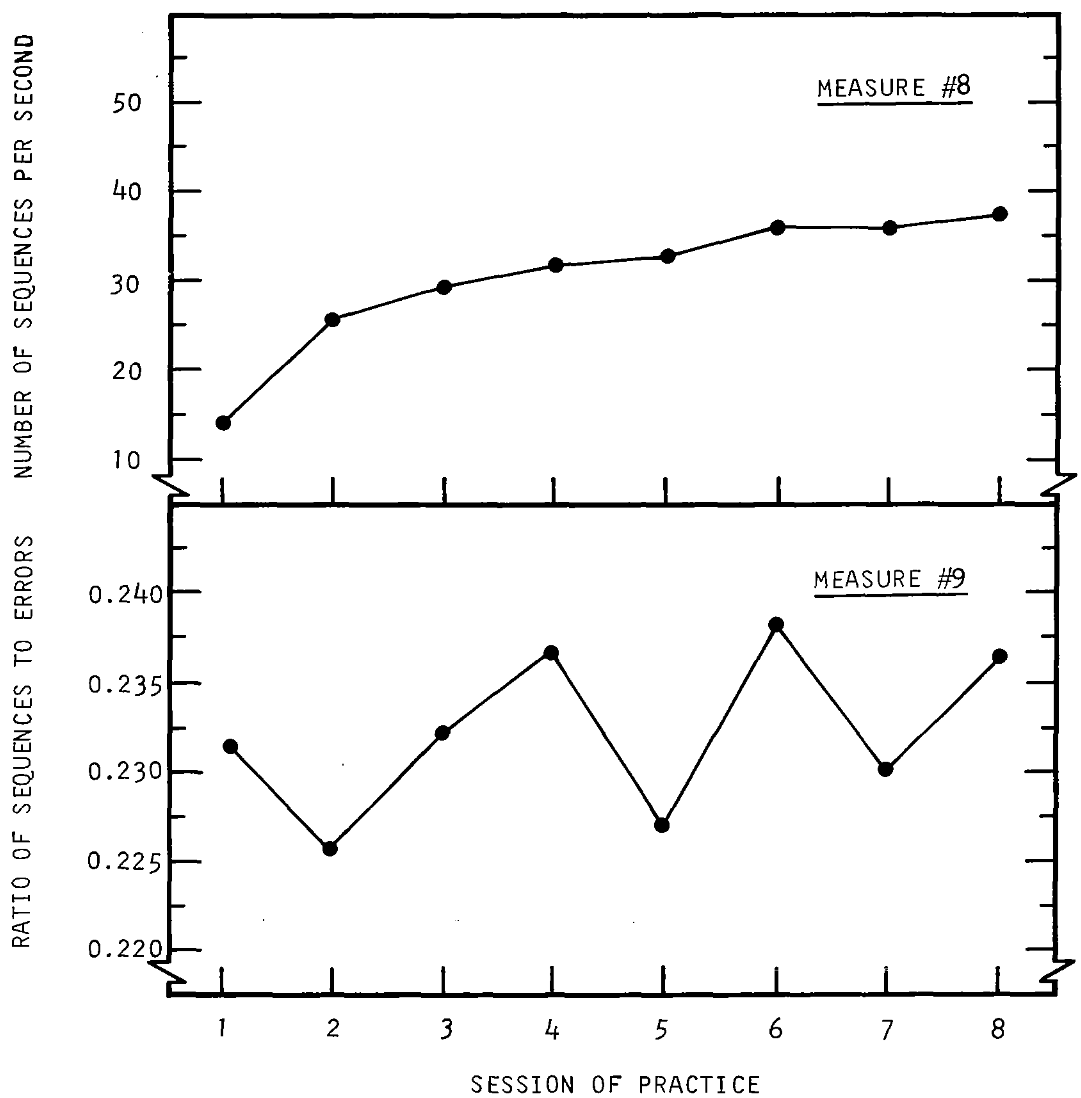

Figure 9.--Mean number of phase-II sequences per second (measure #8), and mean ratio of the numbers of phase-II sequences to phase-II errors (measure #9), as functions of practice. These measures represent factor V: speed and accuracy in phase II.

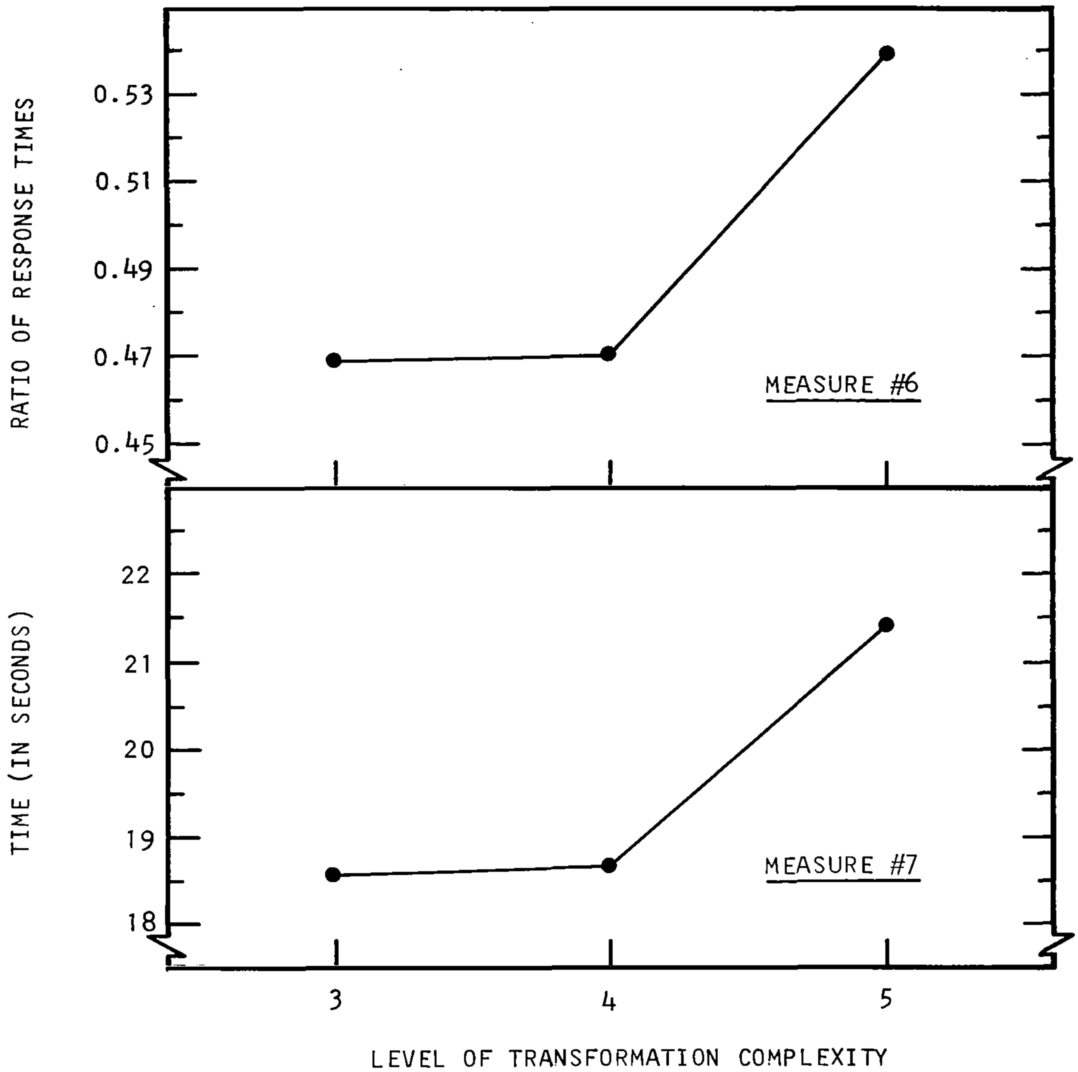

Figure 10. --Mean ratio of phase-III time to average phase-I and phase-II time (measure #6), and mean time per phase-III sequence (measure #7), as functions of transformation complexity in session 8. These measures represent factor IV: time in problem solving.

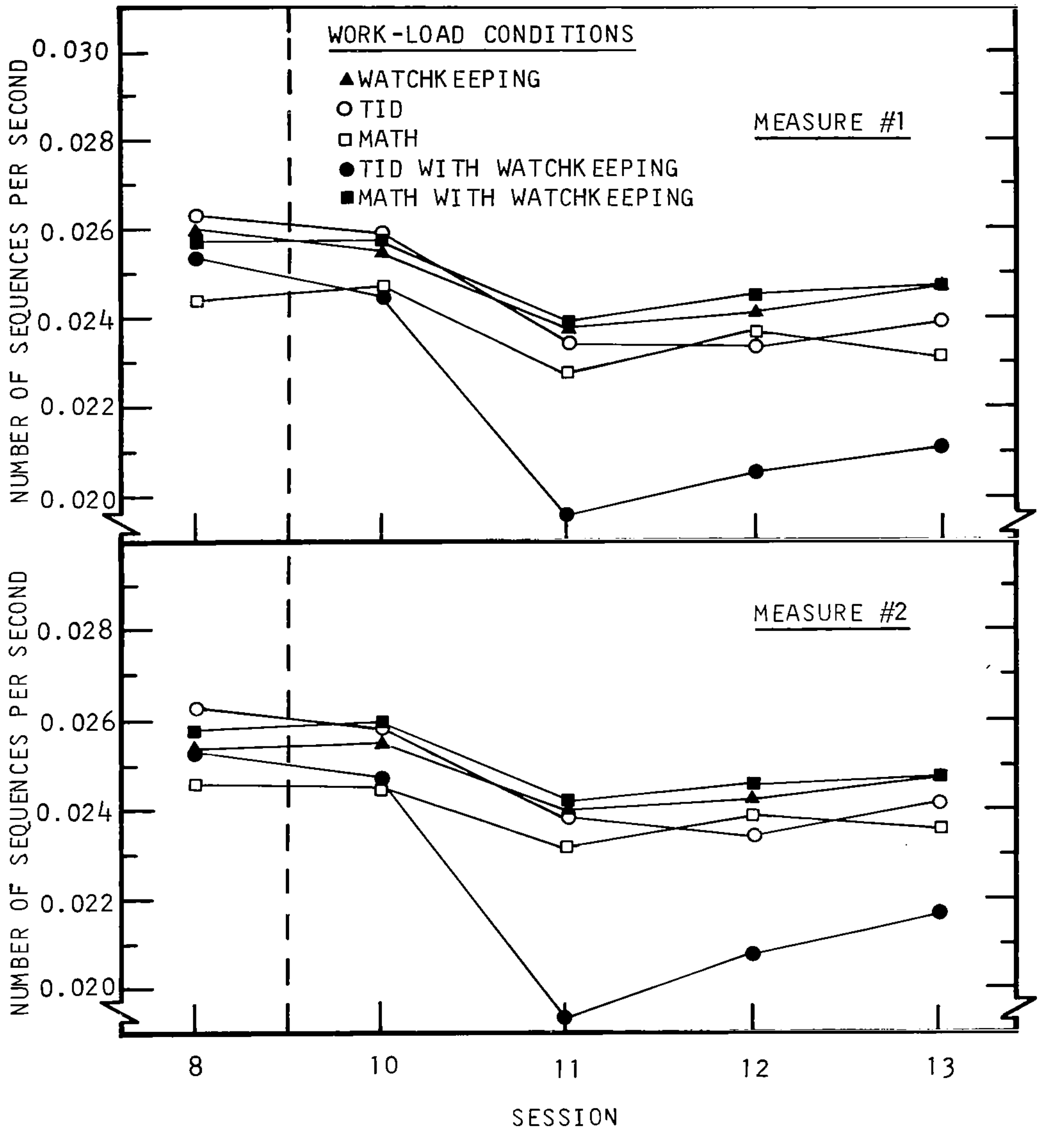

Figure 11. --Mean number of phase-I sequences per second (measure #1), and mean number of combined phase-I and phase-II sequences per second (measure #2), as functions of work-load condition and practice. These measures represent factor I: general accuracy.

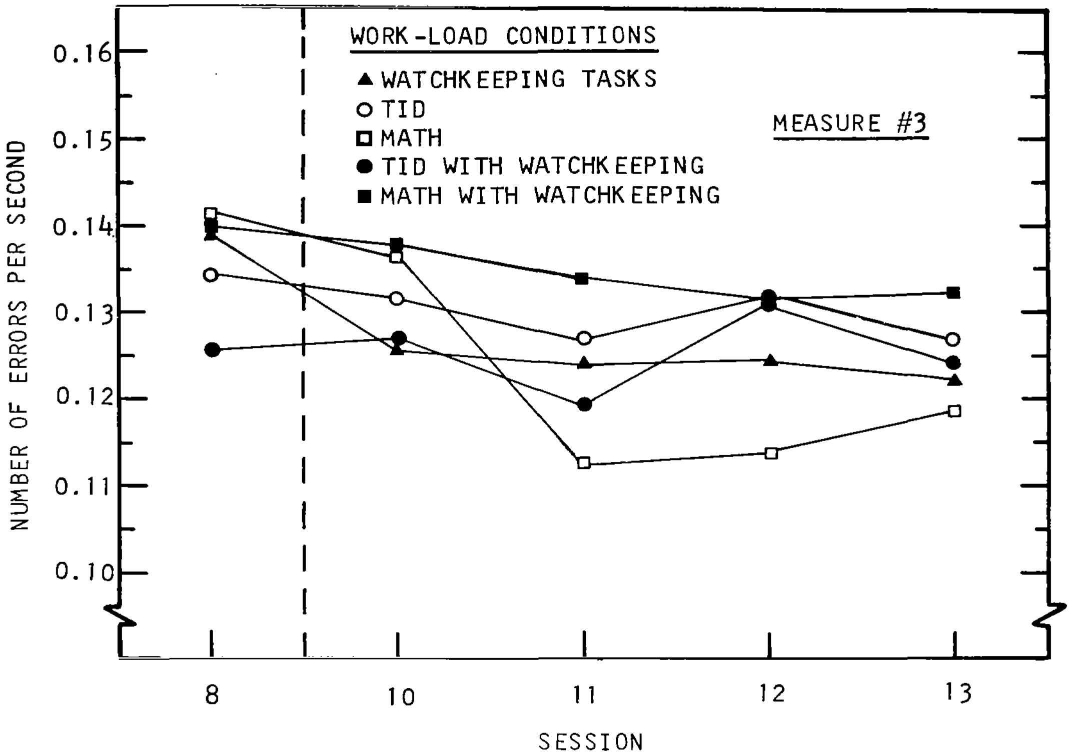

Figure 12. --Mean number of combined phase-I and phase-II errors per second (measure #3) as a function of work-load condition and practice. This measure represents factor II: general response rate.

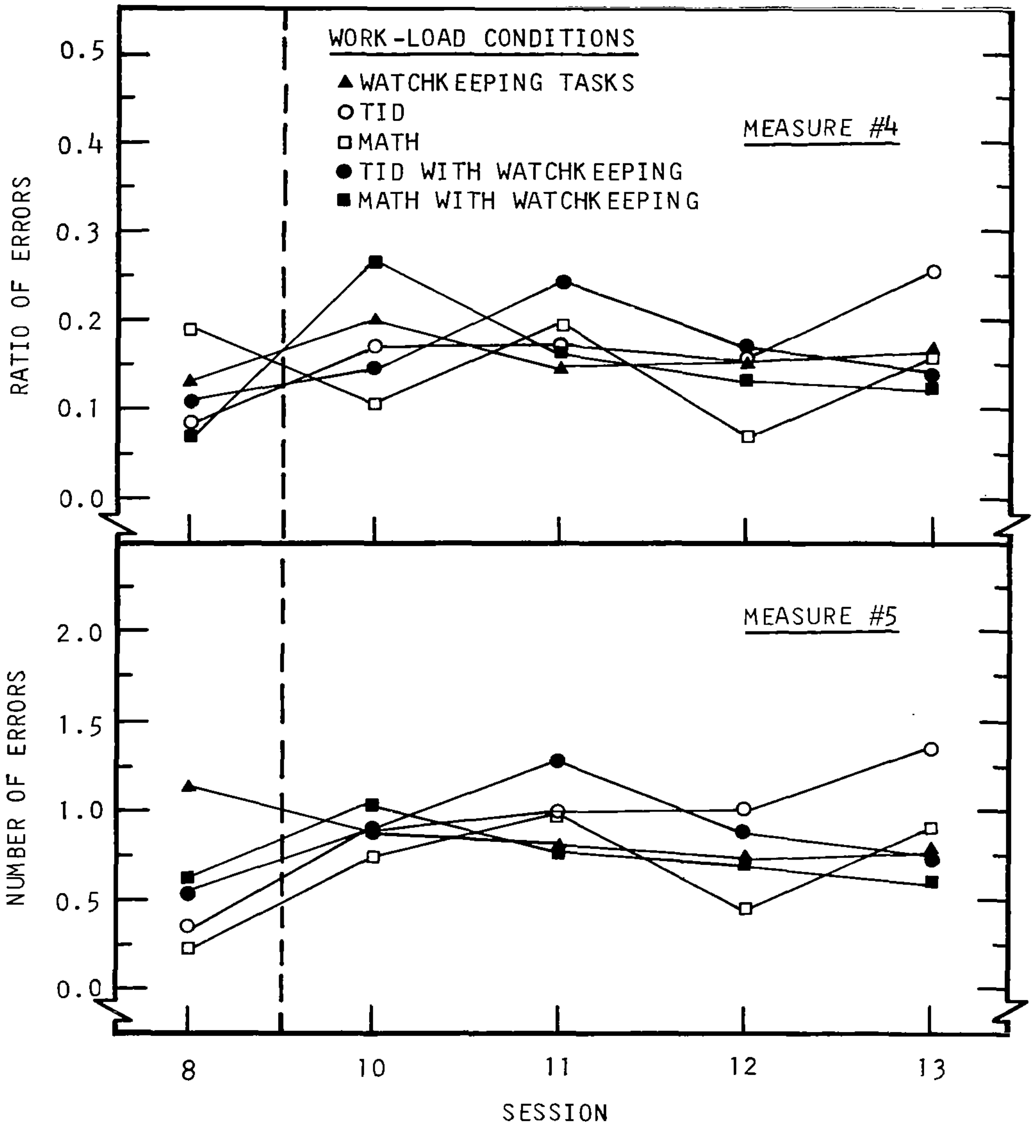

Figure 13. --Mean ratio of phase-III errors to average phase-I and phase-II errors (measure #4), and mean number of phase-III errors per sequence (measure #5), as functions of work-load condition and practice. These measures represent factor III: errors in problem solving.

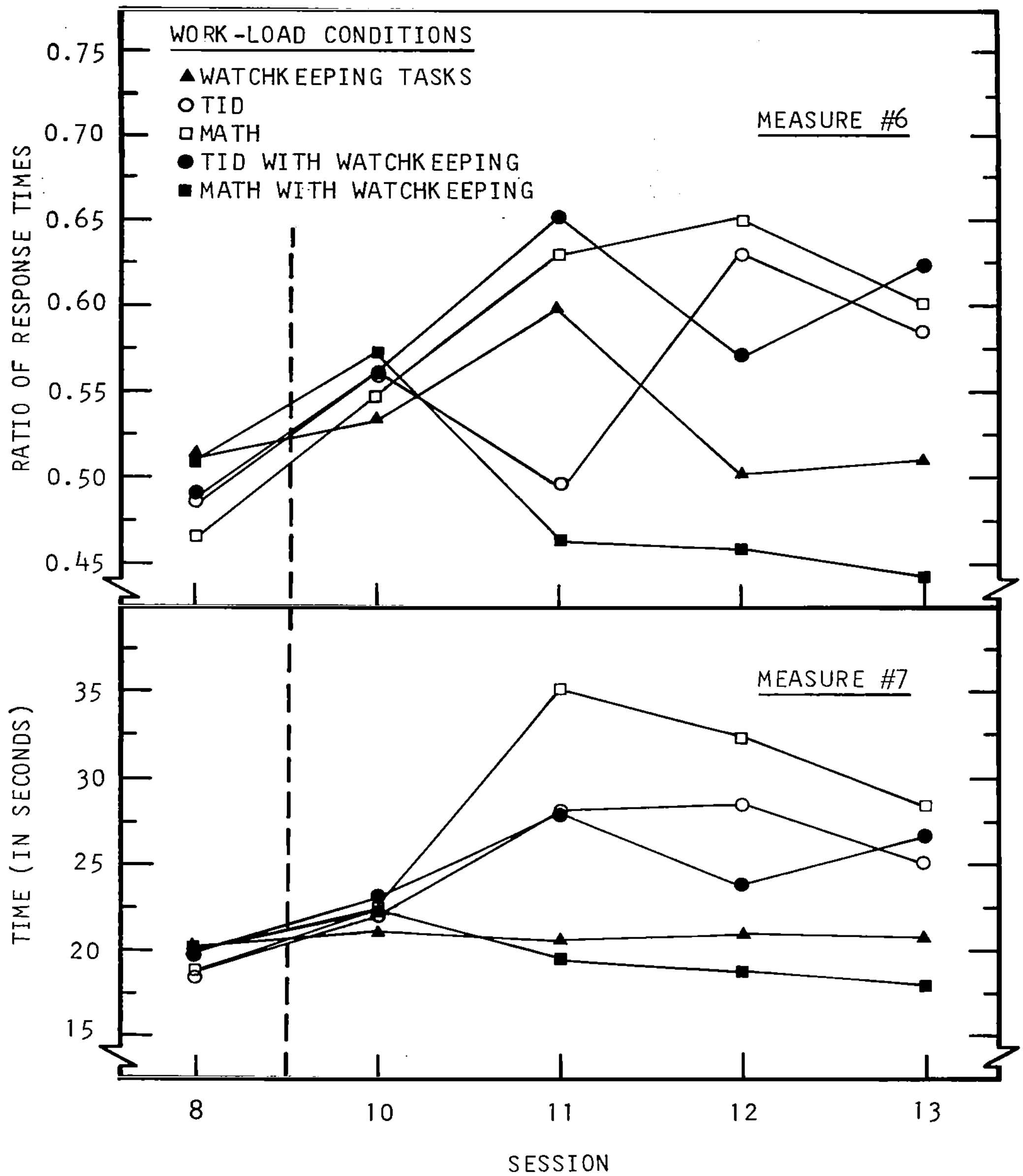

Figure 14. --Mean ratio of phase-III time to average phase-I and phase-II time (measure #6), and mean time per phase-III sequence (measure #7), as functions of work-load condition and practice. These measures represent factor IV: <u>time in problem solving</u>.

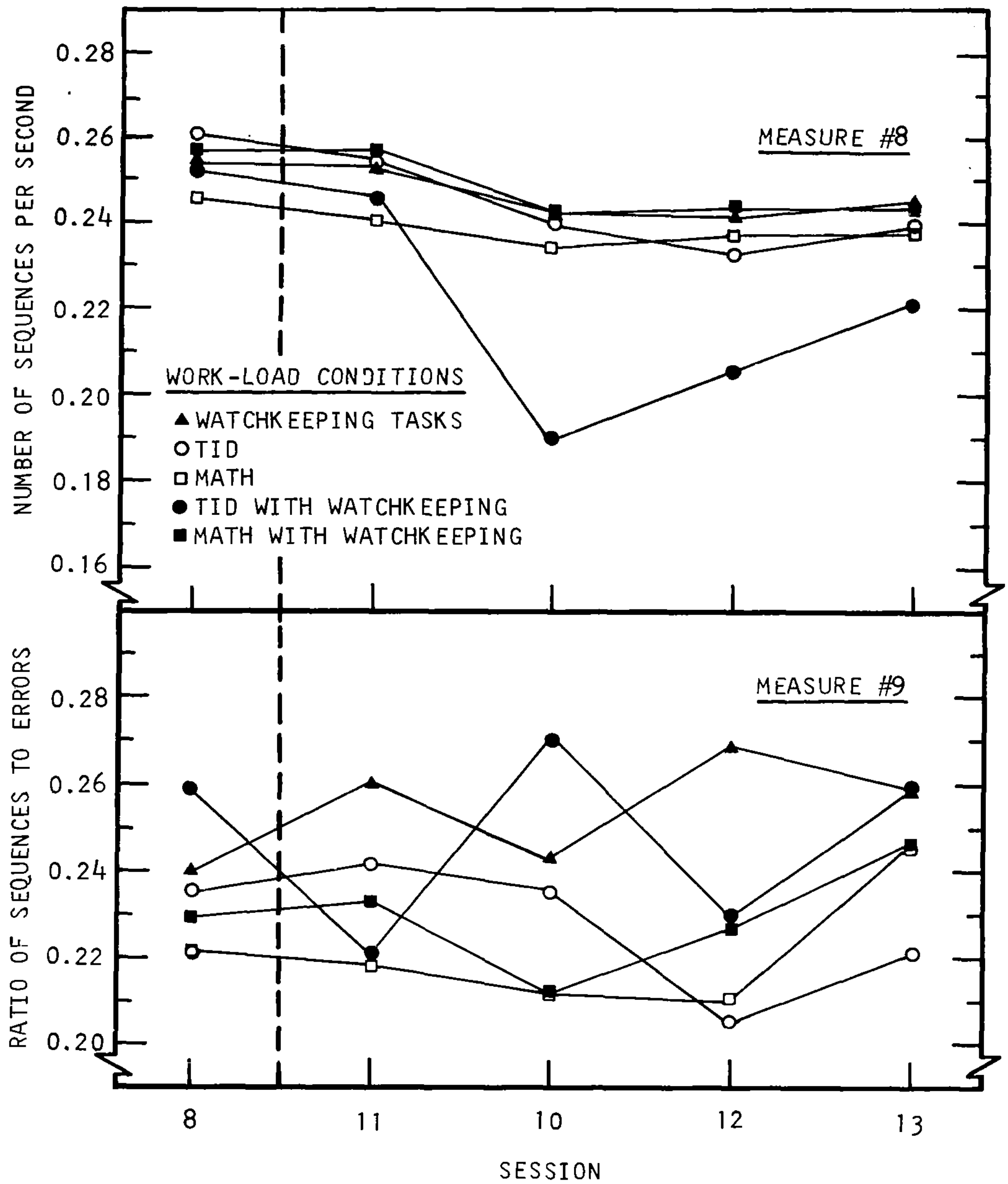

Figure 15. --Mean number of phase-II sequences per second (measure #8), and mean ratio of the number of phase-II sequences to phase-II errors (measure #9), as functions of work-load condition and practice. These measures represent factor V: speed and accuracy in phase II.

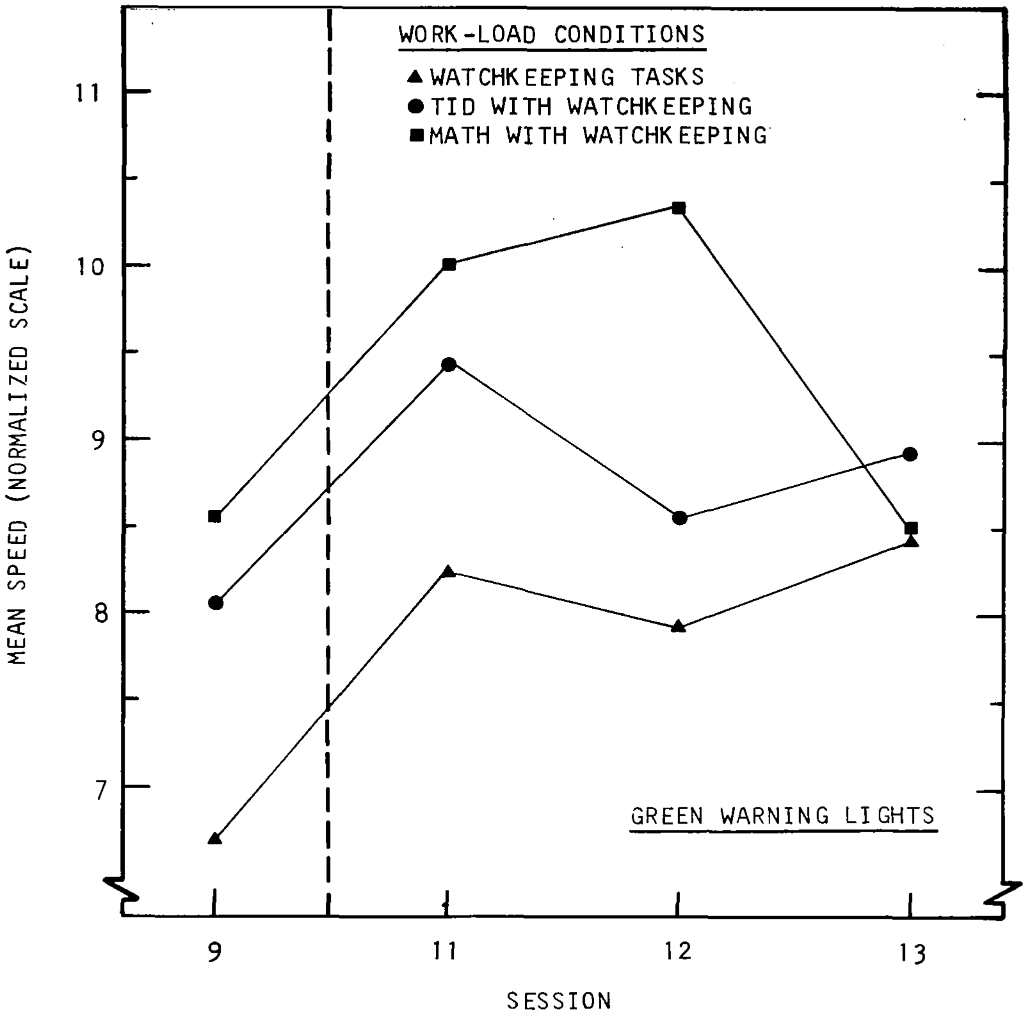

Figure 16. --Mean speed (normalized scale) in detecting green warning-light signals as a function of work-load condition and practice.

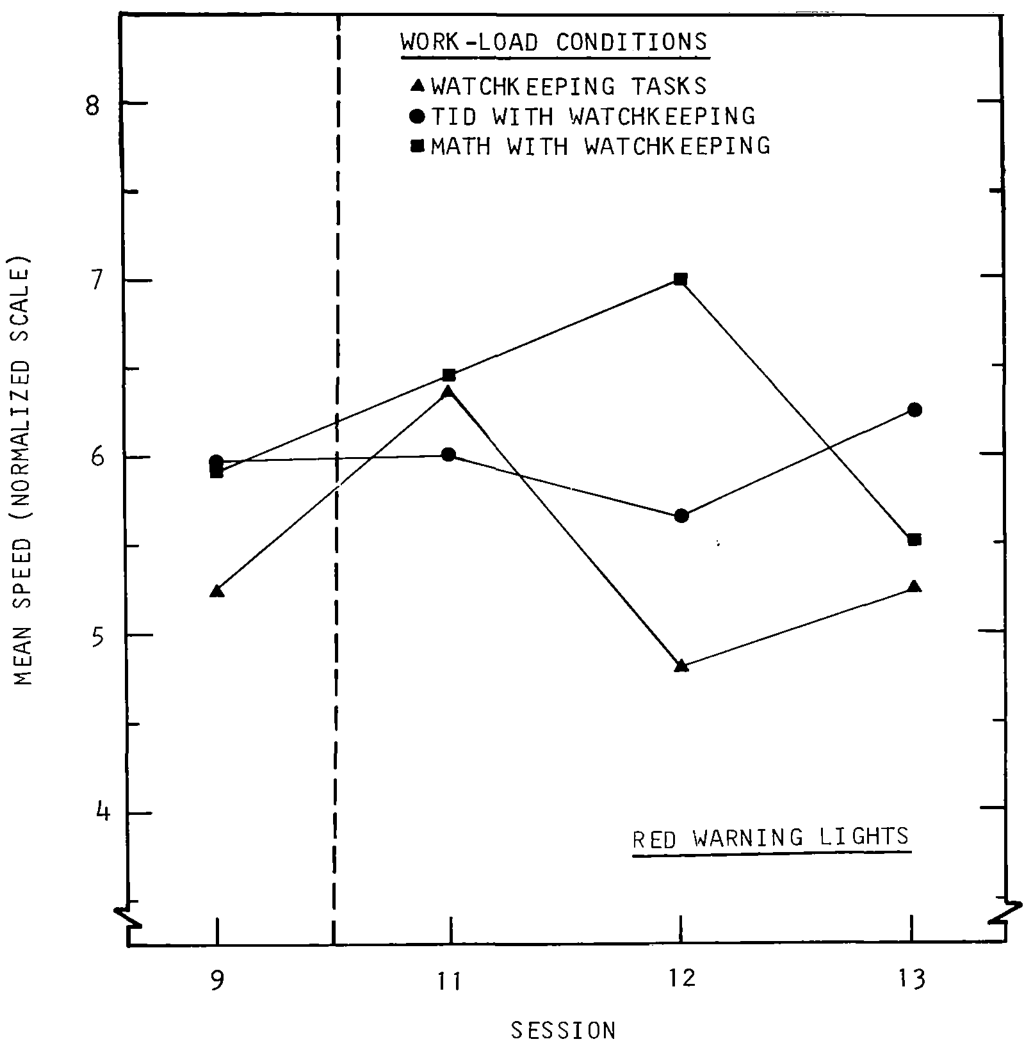

Figure 17. --Mean speed (normalized scale) in detecting red warning-light signals as a function of work-load condition and practice.

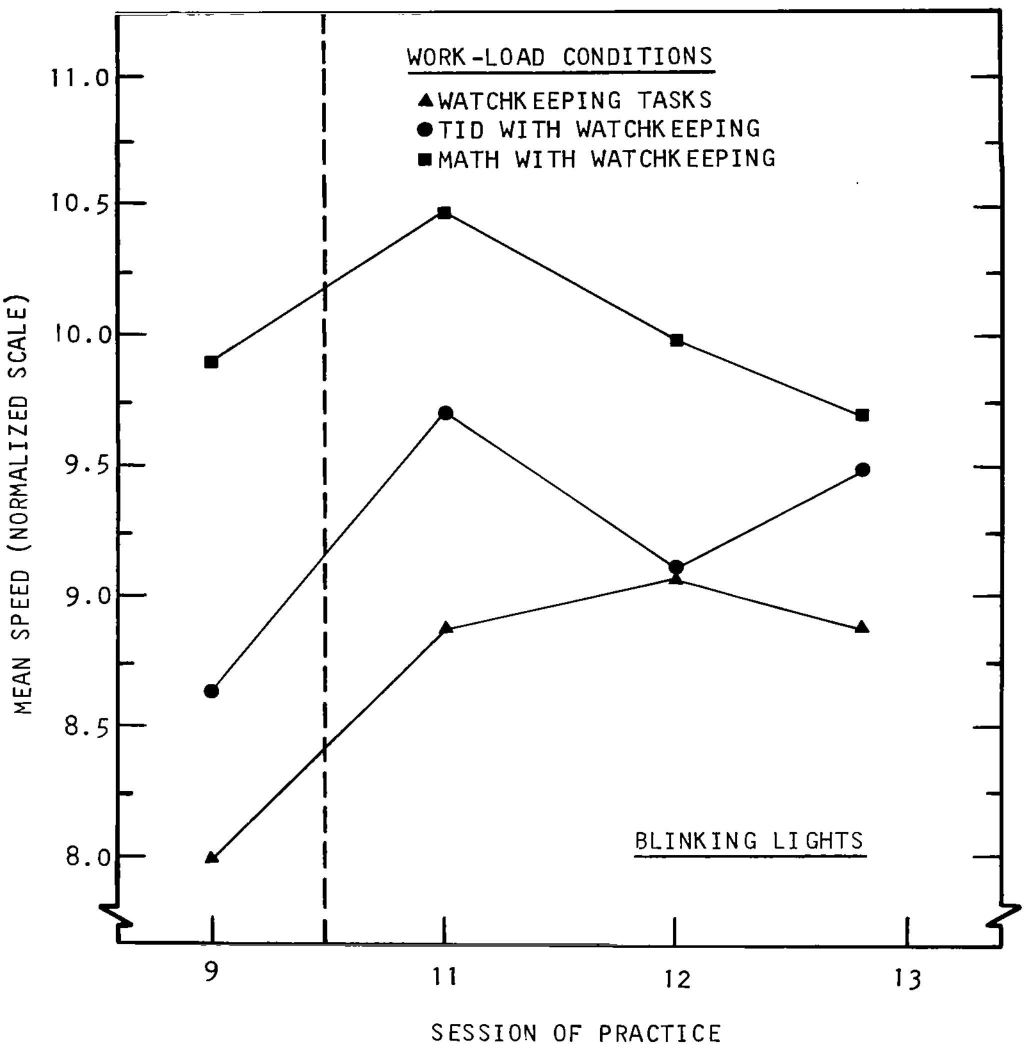

Figure 18. --Mean speed (normalized scale) in detecting blinking-light signals as a function of work-load condition and practice.

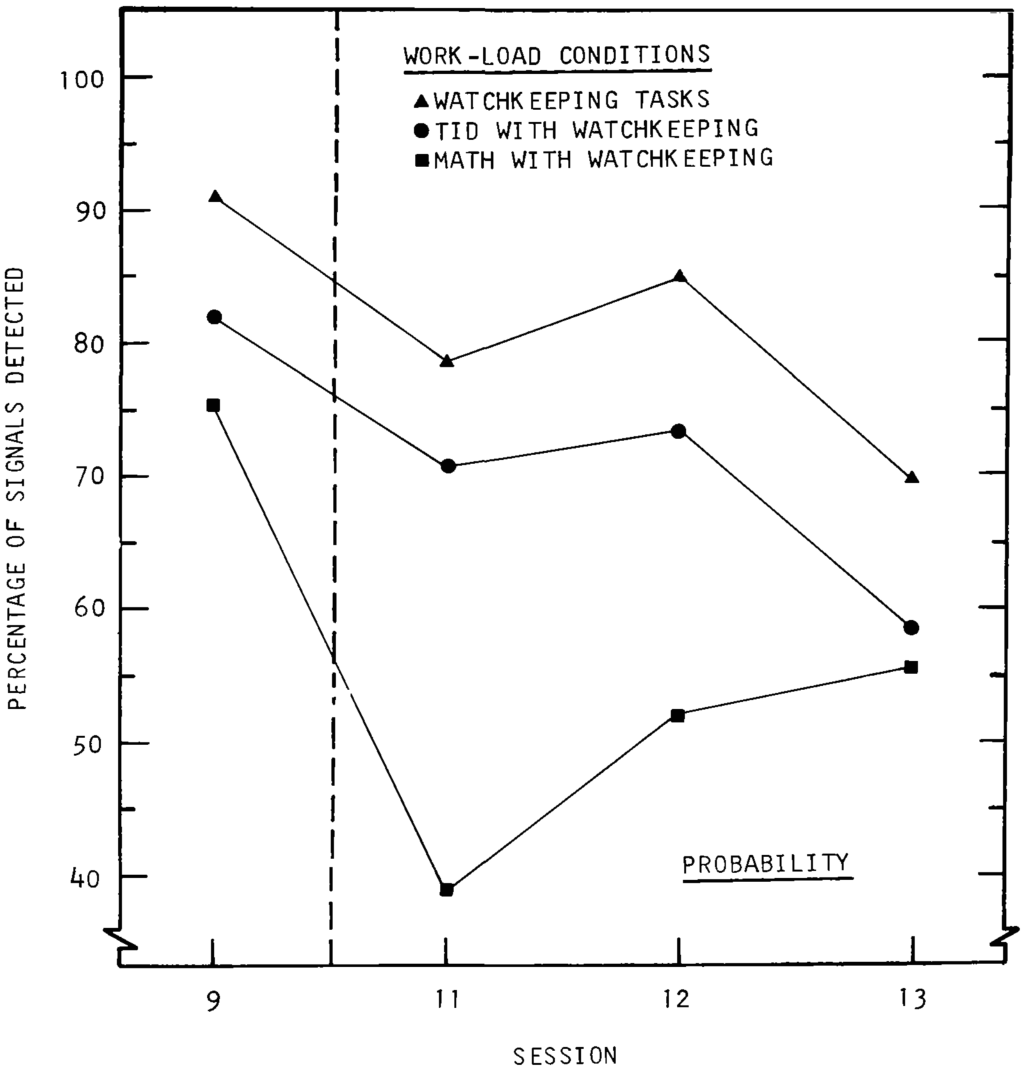

Figure 19. --Mean percentage of correct probability-monitoring signal detections as a function of work-load condition and practice.

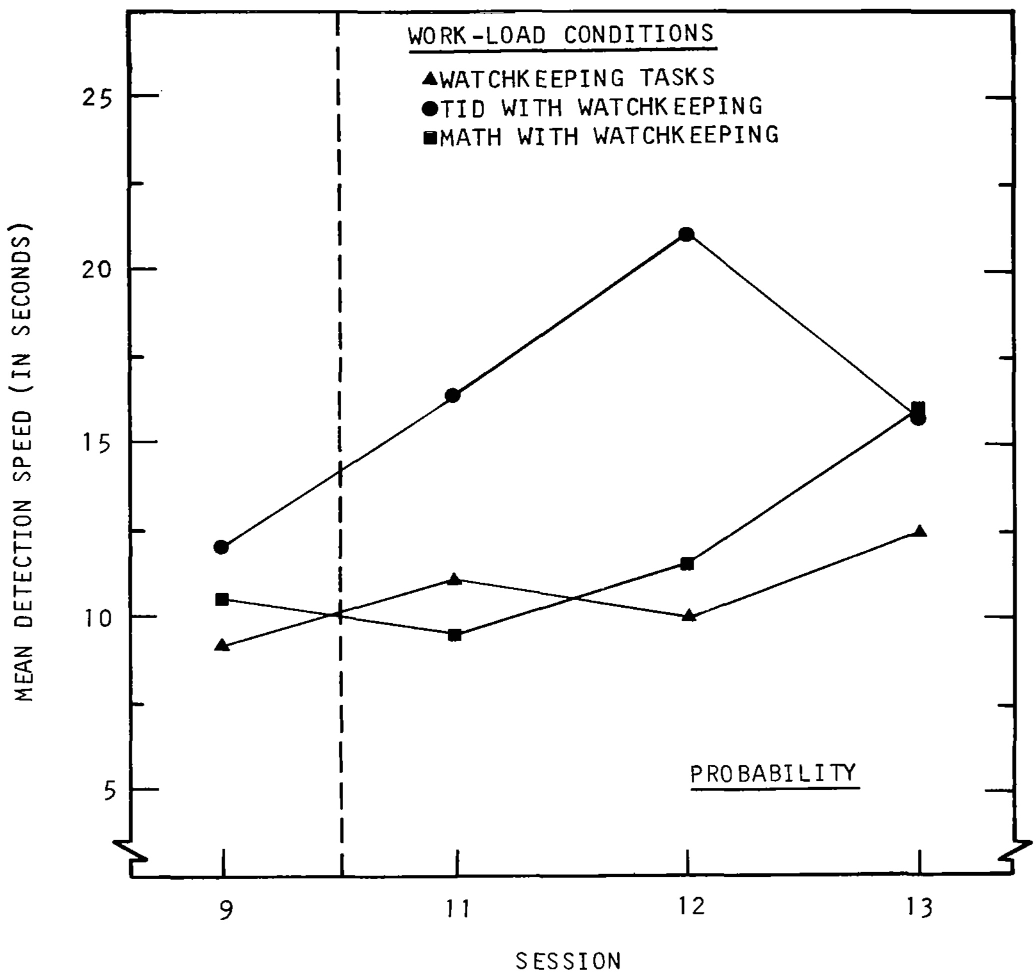

Figure 20. --Mean speed in detecting probability-monitoring signals as a function of work-load condition and practice.

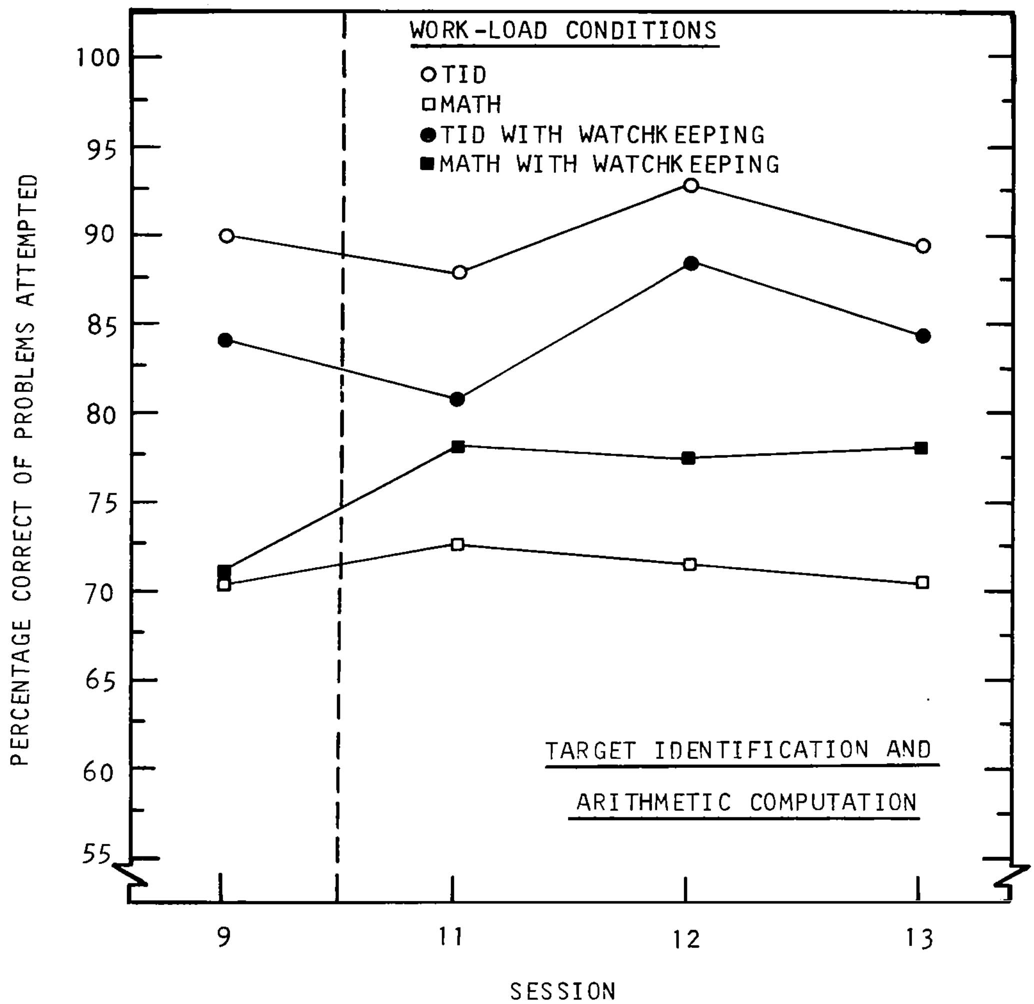

Figure 21. --Mean percentages correct of attempted target-identification and arithmetic-computation problems as functions of work-load condition and practice.

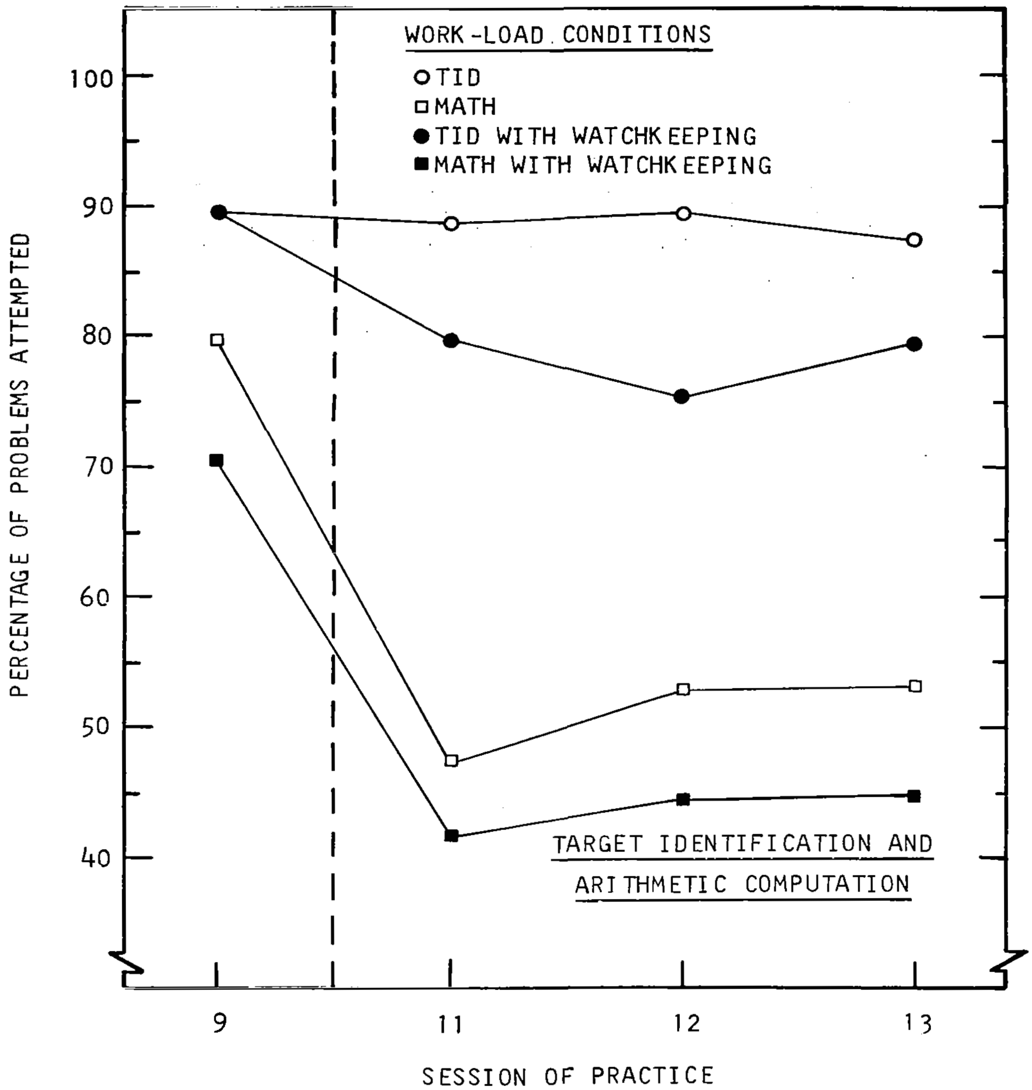

Figure 22. --Mean percentages of target-identification and arithmetic-computation problems attempted as functions of work-load condition and practice.

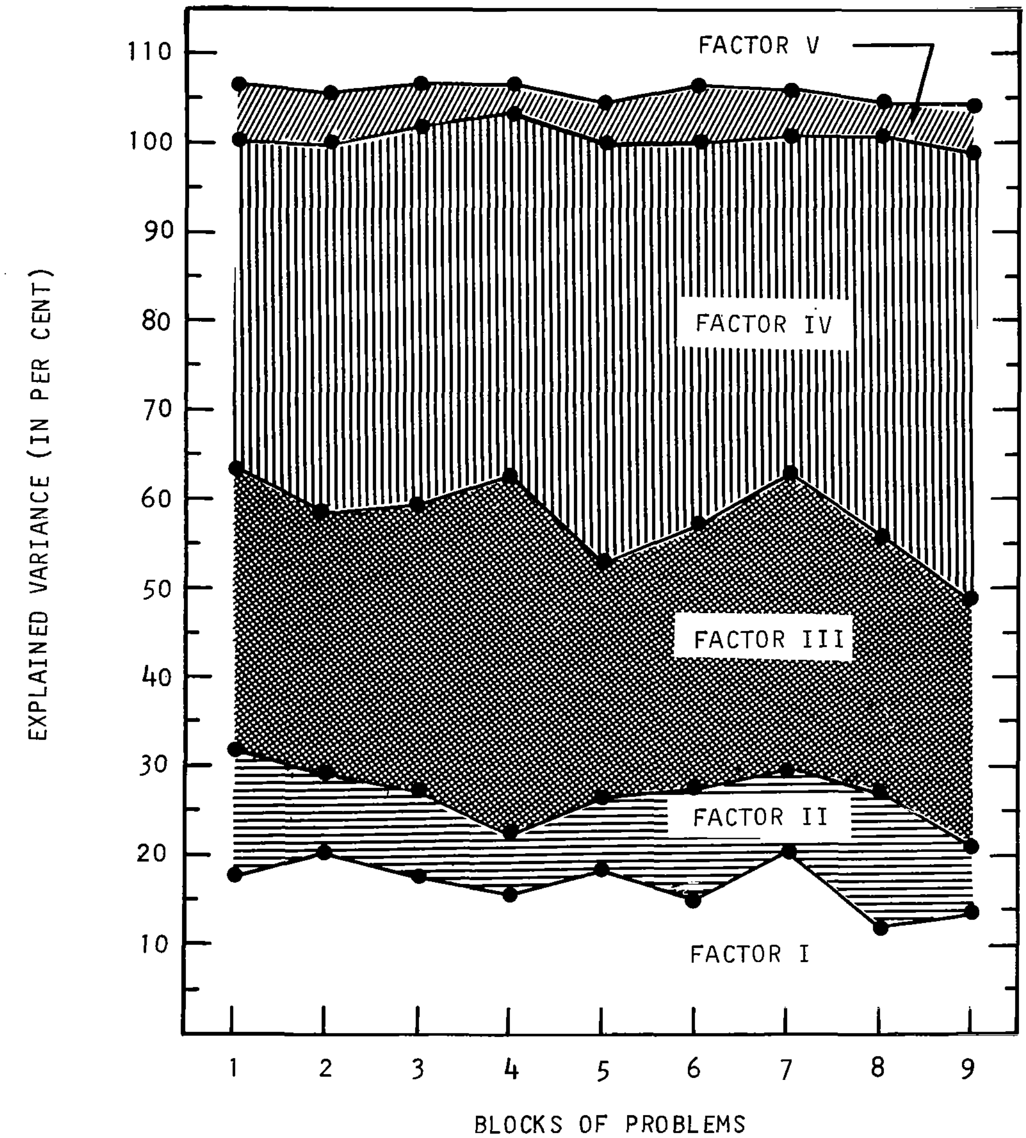

Figure 23. --Percentage of total variance explained by each of five COTRAN factors for each of nine blocks of three problems solved by 20 subjects during session 1.

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