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EXPLORATIONS IN THE AUTOMATION OF SENSORIMOTOR SKILL TRAINING

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ABSTRACT

EXPLORATIONS IN THE AUTOMATION OF SENSORIMOTOR SKILL TRAINING

A system served by a CDC 160-A computer trained Subjects (Ss) to operate a 5-key chord keyset for transmitting 31 binary-coded English letters and numerals. Experiments compared learning rate and terminal performance of Ss trained under different conditions of response prompting and confirmation. Prompting stimuli were (1) lights (automated visual), (2) air jets (automated tactile), and (3) reference sheets (nonautomated). Some Ss received response confirmation; others received none. The discriminability of visual and tactile stimuli was also compared. Stimulus, prompt, and feedback presentations were controlled by the computer, which also monitored and recorded individual performance.

Groups trained with either automated visual or tactile prompts were essentially equal to one another and to the group trained without automated prompting in tests following training. Mean differences among training groups in terminal response accuracy and response speed were not significant. Ss trained with tactile prompts were less variable in response speed than were groups trained otherwise. The tactile prompt group was most variable in response accuracy, however, since Ss experienced differential difficulty in discriminating tactile signals.

Mastering the 31-item code was aided materially by response confirmation, regardless of the presence or absence of response prompting. Mean response accuracy for Ss receiving response confirmation was significantly greater than for Ss not receiving feedback.

Discrimination tests favored visual prompts over tactile prompts in both response speed and accuracy. Tactile stimuli proved difficult for most Ss to discriminate; responses tended to be slower and less accurate as multiple (particularly adjacent) fingers were stimulated.

It was concluded that automating sensorimotor skill training is feasible, and that the utility of computer-served systems for training research appears great. Whether automating skill training is justified by promise of increased effectiveness or economy, however, will require cost/benefit analyses for particular training tasks.

FOREWORD

PURPOSE.

The purpose of this study was to explore the feasibility of using a computer to teach a psychomotor task, i.e., operation of a 5-key chord keyset for binary coding. The other functions studied were mode of presenting prompts (visual, tactual) and effects of feedback upon performance. The automated visual and tactual prompting modes were compared with what might be considered to be a "traditional" mode, in which subjects (Ss) learned the code by referring to a code sheet.

RESULTS.

The results indicated that none of the methods of prompting was superior to the others. However, the fact that Ss could be taught to perform a psychomotor task by means of a computer is a significant advance in training procedures. The results also indicated that the provision of feedback aided performance for each of the prompting modes.

IMPLICATIONS FOR TRAINING AND TRAINING RESEARCH.

Computer-based instruction naturally goes far beyond the ordinary teaching machine in both a quantitative and qualitative manner. The number of training conditions which can be varied is almost infinite and the types of tasks which can be trained include combinations of perceptual, motor, and perceptual-motor activities. Thus, the flexibility of a computer-based instruction system affords it great potential not only as a training device, but as a research tool.

Computer-based instruction makes it possible to provide multiple training stations to accommodate many individuals simultaneously. Psychomotor tasks, such as typing or sending and receiving morse code, could be taught in a multiple training situation. In addition, if the training system were an adaptive one, adjustments in difficulty level and types of learning material could be made according to the capacities of each individual being taught. The effectiveness of such an adaptive system, in multi-station psychomotor training, is a matter to be determined by future research.

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SECTION I

INTRODUCTION

GENERAL

This study evolved from engineering interest in augmenting human intellectual functioning through real-time computer aid. Toward this end, explorations of the man-computer interface showed a need for simplified means for communicating between man and machine in a language intelligible to both. As one approach to this, a binary alphanumeric code was developed and 5-key chorded keysets were fabricated for transmitting messages in this code from man to computer.*

These efforts to improve man-computer communication converged with the interest of engineers and psychologists in using computer-served systems to control and monitor performance in human learning, especially in developing effective techniques for providing continuous, machine-controlled prompts or cues to guide a human learner in the acquisition of sensorimotor skills. Of particular interest was the prospect of using tactile stimuli as a means for prompting discrete motor acts and sequences of acts. (This interest was stimulated in large part by work in tactile communication then under way in the Control Systems Laboratory at SRI under the direction of Dr. James Bliss.)

If the 5-key keyboard and the binary alphanumeric code were to become a practical, useful communication link between man and computer, then effective means must be developed for persons to acquire skill in transmitting the code. Examining such means in a semi-automated, computer-served training system became the focal problem of this study.

BRIEF REVIEW OF SELECTED BACKGROUND RESEARCH

Previous research influencing the planning and conduct of this study falls in three major categories: (1) that bearing on the efficacy of guiding learning through cueing or prompting and knowledge-of-results feedback; (2) that concerned specifically with information transmission on five-key keyboards; and (3) that dealing with the receptivity of tactile stimuli. The following is a partial summary.

FEEDBACK AND RESPONSE CUEING. Perhaps the best current summary of research on media of instruction generally, including effects on learning of response feedback and prompting techniques, is that prepared by Lumsdaine (1962, 1963).† [Much of the same material appears in two

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* The 31-item code used as a learning problem for the experiments reported in this report is reproduced in Appendix A. Expanded five-bit codes are possible, of course, by providing case changes. One such code used at Stanford Research Institute includes all letters, numerals, and symbols of a standard typewriter keyboard.

† References are listed at the end of the report.

separate sources: (1) The Handbook of Research on Teaching, edited by Gage (1963) and (2) Training Research and Education, edited by Glaser (1962)].

With regard to feedback and knowledge of correct response, Lumsdaine (1962, 1963) observes that performance is almost always aided by providing the learner with continuous and immediate knowledge of results during the course of instruction. He points out that the design of many experiments, however, has often confounded results by lumping a variety of degrees and kinds of feedback under such blanket terms as "knowledge of results," "confirmation," "reinforcement," and "correction." Although the mechanisms by which learners accommodate feedback information and use it to increase learning rate or reduce errors is open to different interpretations, it does seem clear that lack of knowledge of results will almost universally lead to inferior learning performance.

Post-response feedback and pre-response cueing or prompting have in common the objective of controlling or reducing errors in practice. Prompting guides the learner prior to his response by providing cues that are later reduced or "vanished" so that the learner can be freed from reliance on them. As Lumsdaine observes (1962, 1963), most research to date has concentrated on (1) the value of prompts as such, in contrast to the value of vanishing, and (2) the learning of verbal materials, in contrast to the acquisition of motor skills.

In verbal learning, the evidence is fairly unequivocal that persons trained under conditions that provide guidance prior to overt responses perform better than those trained without the aid of prompting. In addition, learners supported by prompts tend to make more effective transfer of such learning to new, similar items.

Studies by Cook and Kendler (1956), Cook (1961), and Cook and Spitzer (1960) indicate that paired-associates learning using prompting trials was superior to learning aided by post-response confirmation. Irion and Briggs (1957) also report results favoring prompting over confirmation-correction. Kopstein and Roshal (1961) found simultaneous prompting superior to "staggered" (i.e., delayed) prompting in paired-associates learning.

A series of studies by Angell, Lumsdaine, and others found superiority for partial prompting over complete prompting. This series, summarized by Angell and Lumsdaine, dealt with learning verbal material. With regard to intratrial cueing, they conclude that cueing cannot be too strong, particularly during early stages of learning, since the probability that a correct response will be elicited is greatest when the amount of cueing is also high (Angell and Lumsdaine, 1962).

PERFORMANCE ON FIVE-FINGER KEYBOARDS. Three studies relevant to performance on five-finger keyboards may be cited.

Klemmer and Muller (1953) studied the rate of transmission of information when it was encoded for presentation in five flashing lights; the operator's task was to press keys corresponding to the light pattern. Independent variables were (1) the rate at which stimuli were presented and (2) the number of lights in the stimulus pattern. Subjects (Ss) were highly trained; all Ss had more than six days of practice before the tests began. With highly trained Ss and the performance task as defined above, Klemmer and Muller obtained average response times for all Ss and over all light patterns of approximately 0.4 second. This response time was approached by the fifth or sixth day of practice (1600 stimuli were presented each day). Instructions to Ss probably influenced response speed to some extent, for Ss were told in advance which bulbs were possible and what the stimulus cycling rate would be. Klemmer and Muller do not report error scores as such, but response accuracy may be inferred from data reporting information transmitted in bits per second. These data indicate that Ss became overloaded when the stimulus presentation rate was in the range of 2 to 3 stimuli per second; beyond this point, response accuracy deteriorated rapidly for all Ss.

Operator performance on a chord keyboard in response to visual light stimuli was also studied by Ratz and Ritchie (1961). Their experiment used 31 chord patterns identical to those used in this study, although no alphanumeric meaning was assigned to any of the chords. As in the Klemmer and Muller study, the performance task involved striking chords appropriate to visual stimulus patterns. Response times obtained by Ratz and Ritchie were considerably longer than those found by Klemmer and Muller; the median response time for all chords was 1.16 seconds. Although they do not report the amount of pre-test training their Ss received, it apparently was not great. Practice was limited to 10 minutes per day and little improvement in response time was observed after the second day. Ratz and Ritchie interpret their findings in terms of coding theory to estimate the maximum information transmission rate through a man-machine link that might be achieved with such a keyboard and a compatible stimulus display.

Seibel (1961) also studied discrimination reaction times for highly trained Ss responding to 31 chord patterns on a 5-key keyboard. The problem task was similar to that set by Ratz and Ritchie. In contrast to Ratz and Ritchie, however, Seibel achieved very fast response times--0.30 to 0.35 second on the average by four Ss for all chords. Seibel also found a high correlation (.836) between average response time and percent error for the 31 chords. The over-all error rate was 9.9 percent. One notable feature of Seibel's experiment was that discrimination reaction times continued to improve throughout the course of observations, or up to 11,000 trials. This stands in contrast to Ratz and Ritchie's suggestion that asymptotic performance is approached within the first few hundred trials (Ratz and Ritchie, 1961). It also suggests that the proficiency limit for discriminate responding is even beyond that obtained by Klemmer and Muller (1963).

RECEPTIVITY OF TACTILE STIMULI. Interest in tactile stimuli as a means for presenting response prompts in the keyboard learning problem grew from a search for manipulable and painless stimuli rather than from special theoretical interest in cutaneous sensibility as such. Certainly it was known that the palmar side of the fingers were pressure-sensitive and had a narrow two-point threshold compared to most other body areas. Observation of experimentation by Bliss in "tactile communication" experiments (Bliss et al., 1963, 1964) encouraged the impression that air pressure would provide a practical means for directing controlled stimulation.

The general literature on cutaneous sensitivity [see Geldard (1961), for example] offered support for the notion that tactile stimuli would provide discriminable prompts to guide finger responses. No reported specific instance was found in which air pressure had been employed in quite the manner envisioned for this experiment. Findings by Bliss and Massa (1961) suggested that accurate discrimination of tactile stimuli would probably be found difficult, especially in patterns involving multiple fingers not widely separated from one another. But the virtues of air pressure as an easily controlled, focusable, and nonpainful stimulus that could be differentially directed to the fingers overrode reluctance to use such stimuli based on available reports of difficulties in stimulus discrimination.

SECTION II

STATEMENT OF THE PROBLEM

The aim of this study was to explore the effectiveness and feasibility of automating sensorimotor skill training. Feasibility was investigated through an experimental study incorporating automated prompting procedures. The general hypothesis was that automatically presented response prompts would aid the development of the sensorimotor response patterns required for skilled performance.

Subjects were trained to operate a 5-key chord keyset for transmitting 31 binary-coded English letters and numerals. Through paired associations, Ss learned (1) to associate chord patterns with their appropriate alphanumeric character, and (2) to perform the motor responses required to strike each of the chord patterns on the 5-key keyset.

SECTION III

METHOD

COURSE OF THE STUDY

The study progressed in three identifiable phases. The first phase was devoted to the design, testing, and refinement of the ancillary equipment and programs that composed the training system. During the second phase, a series of exploratory experiments were carried out to examine the effects of variations in prompting techniques and response feedback upon learner performance. Analysis of the accumulated data comprised the final phase.

Work on the project was initiated on 15 January 1964, and the Work Plan was submitted to the U.S. Naval Training Device Center in February of 1964. Development and preliminary testing of input-output devices, displays, and programs required approximately two elapsed months. The main series of experiments took place during September and October, and a supplementary series was carried out during December.

SYSTEM DEVELOPMENT AND PRELIMINARY TESTS

The initial tasks entailed developing (1) appropriate input-output devices and displays, and (2) programs for controlling training conditions, for monitoring and recording performance, and for executing off-line analyses of performance records.

The first need was for a 5-key keyset suitable for presenting computer-controlled tactile cues to prompt the formation of chords associated with characters in the 31-item code (shown in Appendix A). These keysets were designed from ones developed prior to the present project for internal use at SRI. The design was considered adequate for the exploratory studies then envisioned, and keysets used in subsequent experiments were built to the same dimensions.

The second need was for a display to present the stimuli to the subjects. A system was devised that used a symbol generator to provide a cathode ray tube display of the alphanumeric characters upon command from a computer. Visual presentations were coordinated with the prompting stimuli through the computer programs. All stimulus and prompt presentations were under the continuous control of a CDC 160A computer, which also monitored and recorded the performance of each subject.

The first experimental version of a tactile-cue keyset is shown in Appendix B, and described there in detail; it provided tactile cues through small air jets mounted adjacent to the outer end of each key so that a pulsating air flow could be directed to one or more fingers. A valving mechanism controlled air flow up to 120 cps. Valving mechanisms first used for the air-jet cueing system proved unreliable and inaccurate, thus necessitating a change in design and replacement of the original valving equipment. A slight variation of the mode of presentation of the tactile cues to the fingers was also tested (see Discussion, Section V).

In the original plan of the study, only tactile prompts directed to the fingers were considered. As the study evolved, it appeared desirable to compare the effects of tactile prompts and visual prompts; therefore, techniques for presenting visual prompts in association with the alphanumeric characters were incorporated into the training system and also were examined experimentally.

EXPERIMENTATION AND ANALYSES

PRELIMINARY EXPERIMENTS. Preliminary experimentation with single Ss was begun during April to (1) examine the discriminability of the air-jet cueing patterns and (2) estimate the relative difficulty of forming various chord responses. At this time, equipment and program elements permitted operation with only a single S at a time.

During this pretraining stage, Ss received only tactile cues from the air-jet-equipped keyset. Findings from this stage suggested the need for systematic examination of the extent to which errors made in response to the tactile (air-jet) stimuli were due to (1) problems in accurate discrimination of tactile cues and (2) difficulties in forming particular chord patterns (e.g., those requiring flexion of the third or ring finger) Accordingly, a system for providing visual cues was devised so that responses to tactile cues could be compared directly with responses to visual cues.

The capacity of the system was adequate for multiple station operation. Two stations could be served simultaneously and independently with the display subsystem developed for single-station operation. Since the costs of expanding the display subsystem beyond two stations more than offset the economies resulting from fuller utilization of the computer, it was decided to restrict the system to two-station operation. As modified, the system employed three Ss simultaneously; two worked at training keyboards while one rested.

By following a schedule such as that tabulated below, it was possible to provide each of three Ss with 32 minutes of practice time in 48 minutes of operating time. Even with the brief delays encountered in shifting stations every 4 minutes, entering subject identification numbers in the record tape, etc., it was found possible to achieve 48 minutes of operating time in less than 60 minutes total time.

Time Period	Station A	Station B	Rest
0-4	1	2	3
4-8	1	3	2
8-12	2	3	1
12-16	2	1	3
. . . . Etc.			

PILOT STUDY. The first series of experiments wherein the performance of Ss trained according to different techniques could be compared began in late July and extended into August. All subjects used in these and later experiments were female, age 18 or older, high school graduates or more, right-handed, and experienced touch-typists. Three Ss were trained over 7 consecutive workdays, each under a different training condition: (1) one S received response prompts from the tactile cue (air-jet) keyset, (2) one S received response prompts from the visual cue (light panel) keyset, and (3) one S received no automated response prompts but was provided with a code sheet for reference during practice sessions. Training and testing sessions were scheduled for one hour each day. During this period, each S accumulated a total of 176 minutes of combined practice and testing time at her respective keyboard while working on a schedule of 8 minutes practice followed by 4 minutes rest. Discrimination tests for each S were also included in this regimen.

Findings from these pilot experiments are reported in Section IV. This series also provoked some procedural changes that were incorporated into subsequent experimentation.

MAIN SERIES. The main series of experiments followed the general plan of the pilot study. Three different training conditions (automated tactile prompting, automated visual prompting, no automated prompting) were compared by training three groups of six Ss each for five consecutive days. The following changes in experimental conditions were made for this series:

(1) Only those six Ss who were to learn the code through memorization and drill with the code sheet had access to a code sheet and then only during those periods when they were actually practicing at a keyset. (In the pilot study, Ss had been shown the general format of the code and had been allowed 5 minutes to review the code prior to their first practice session each day.)

(2) A second tactile-prompt keyset was developed in which the air jets were mounted directly in the keys rather than adjacent to the keys. Performance with this keyset was compared to that of the original to see if the locations of the air nozzles would improve discrimination of the tactile prompting signals.

(3) Some programming modifications were made to make both the control and the analytical programs more flexible. To increase flexibility in control of the training conditions, the program was modified slightly to permit varying the time delay between the presentation of the primary stimulus (the alphanumeric character) and the prompting stimulus (either a tactile or visual signal) with each 4-minute session. The analytical program was modified slightly so that summary printouts showing aggregated numbers and times of correct responses, error responses, and total responses could be obtained without hand-tabulating the stimulus-response printout matrix.

These experiments with 18 Ss were conducted during the period from 14 September through 2 October 1964. Results from this series, including comparisons of performance under the three different training conditions, are shown in Section IV.

SUPPLEMENTAL SERIES. A final round of experimentation was carried out during the week of 7-11 December 1964. Two groups of three Ss each participated during this period. One group of three Ss was totally unfamiliar with the experiment and the equipment; this group was comparable in general background to the subjects who had participated previously. Each of the three Ss in this group was randomly assigned to one of three training conditions previously described--automated tactile prompting, automated visual prompting, or no automated prompting. The main difference from previous experiments was the introduction of a response feedback signal to indicate to the S what response she had actually made to each stimulus. By comparing the feedback character with the original stimulus character, Ss could ascertain immediately whether their response was correct or incorrect. The purpose of the experiment with these three untrained Ss was to examine the effects of immediate response feedback upon the acquisition of chording skill and accuracy.

The remaining three Ss were ones who had participated during one of the experimental weeks from 14 September through 2 October. These Ss were brought back for retraining to provide estimates of (1) retention of skill from previous training, and (2) response speed that might be achieved over a longer period of training.

All six Ss who participated during the December sequence also were tested for discrimination of the visual and tactile prompts.

SECTION IV

RESULTS

The results from tests to determine the speed and accuracy with which tactile and visual prompts could be discriminated are presented in Tables 1-3. These findings include data from discrimination tests administered at different times to nine Ss.

The results from various comparisons of the three training methods examined, i.e., training with automated tactile prompting, training with automated visual prompting, and training without automated prompting are presented in Tables 4-10 and Figures 1-5. The data are from the pilot study carried out with three Ss from 30 July through 7 August and from the main series of comparative studies with 18 Ss carried out from 14 September through 2 October, and evidence regarding the effects of feedback on performance is drawn from comparisons of the performance of three Ss trained during the supplementary series in December to the performance of 18 Ss trained in September-October. Finally, some indications of upper limits of response speed are suggested by data from the three Ss who were retrained during the supplementary series in December. Figure 1 indicates the number and characteristics of the Ss, and the chronology and type of studies conducted.

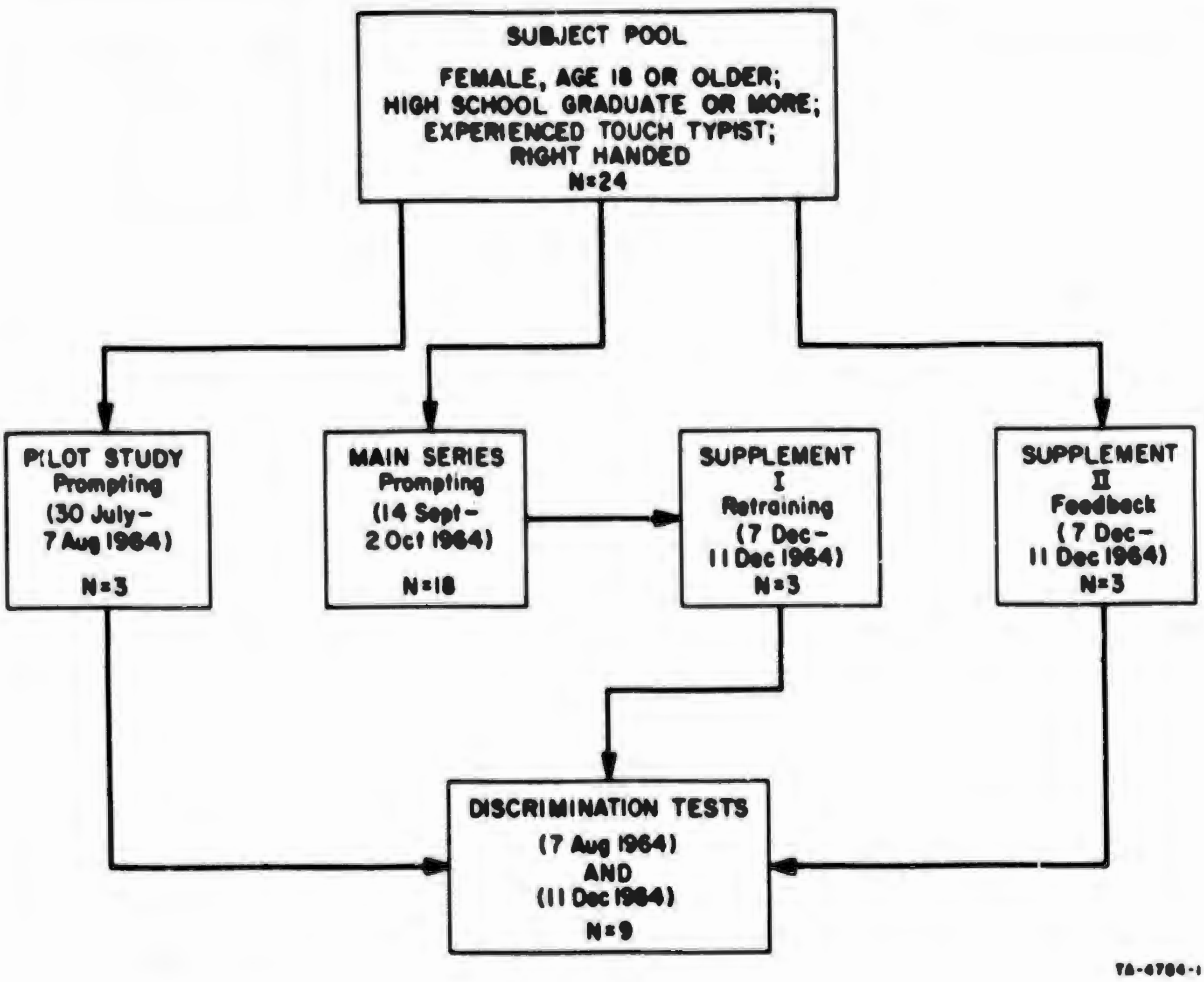

FIG. 1 DIAGRAMMATIC REPRESENTATION OF STUDIES AND TESTS

DISCRIMINATION OF TACTILE AND VISUAL PROMPTING STIMULI

During the developmental stage of the project, a number of persons performed on the air-jet keyset for varying numbers of trials to generate data bearing on (1) the discriminability of the air-jet cues and (2) difficulties in making the chord responses. The performance of some Ss was recorded for as many as 4000 trials. The response problem was simply to strike the chord corresponding to the pattern of air-jet stimulation. Data from these preliminary trials suggested that over-all error rates for the first 15 chord patterns (A through O in the code shown in Appendix A) becomes asymptotic to about the 1.0 percent level after some 2000 trials. For Chords 15 through 31, the error rates remain as high as 15 percent or more for as many as 4000 trials.

A review of these data indicated that difficulties were commonly encountered on chords that involved the little finger and/or the third finger, but not the fourth finger; a high proportion of errors appeared to be caused by flexion of the fourth finger when it was not appropriate. However, since rank correlations of chord difficulty were similar to those reported elsewhere (cf. Seibel, 1961, Ratz and Ritchie, 1961), it was hypothesized that Ss could discriminate air-jet tactile patterns as well as the Ss discriminated patterns of light in chord keyboard experiments conducted by others.

Further analysis of pretraining period data suggested, however, that while anatomical factors might restrict both the speed and accuracy with which complex chords could be struck, response errors might also be accounted for by difficulties in discriminating stimuli directed simultaneously to more than one finger--in particular, to adjacent fingers. To develop some estimate of the proportions of total response error attributable to problems of discriminating the tactile stimuli and to difficulties in forming complex chords, it appeared desirable to compare visual and tactile stimuli as response cues. Accordingly, a visual prompting system was developed to provide a response-prompting procedure to compete with the tactile stimuli.

Nine different Ss participated in tests to determine the relative discriminability of visual versus tactile stimuli as response prompts. Discrimination tests were administered at the end of from one to two weeks of training with the code on the keysets. Tables 1 through 3 summarize the performance of the nine subjects on these tests. Tables C-1 and C-2 in Appendix C show the combined performance of all 9 Ss on both the tactile and visual stimulus discrimination tests.

As shown in Table 1, Ss were highly variable in performance on the tactile stimulus tests. Subjects varied particularly in the ability to discriminate the stimulus patterns accurately; accuracy scores range from 23.1 percent correct to 90.0 percent correct. The rank correlation between Ss' over-all response speed and accuracy on the tactile-stimulus discrimination test was actually negative (rho = -.200), although the magnitude of this relationship is not statistically significant.* Two of the nine Ss accounted for most of this lack of relationship between speed and accuracy. Subject 23 ranked 9th in speed and 1st in accuracy; Subject 13 ranked 2nd in speed and 8th in accuracy.

* See Table C-3 in Appendix C for intercorrelations among Ss on various scores.

Table 1

DISCRIMINATION OF TACTILE PROMPTING STIMULI[a]

Subjects' Previous Training	Subject Number	Total Number Responses	Percent Correct Responses	Mean Response Time (seconds)		
				All Responses	Error Responses	Correct Responses
Tactile Prompts (air jets)	1	144	76.4	1.75	1.89	1.71
	13	78	46.2	1.28	1.42	1.11
	23	50	90.0	3.29	1.08	3.54
	Mean for Group[b]		70.9	2.11	1.46	2.12
Visual Prompts (lights)	2	142	57.0	1.79	2.02	1.63
	12	75	52.0	1.48	1.47	1.48
	22	63	54.0	2.14	2.56	1.79
	Mean for Group[b]		54.3	1.80	2.02	1.63
Without Prompts (code sheets)	3	130	23.1	1.99	1.99	1.98
	11	83	61.4	1.24	1.31	1.20
	21	78	73.1	1.54	1.38	1.59
	Mean for Group[b]		52.5	1.59	1.56	1.59
Mean for All Subjects[b]			59.2	1.83	1.68	1.78
Standard Deviation for All Subjects			18.25	0.588	0.337	0.673

[a] Eight-minute discrimination tests for Ss 1, 2, and 3 conducted on 7 August 1964. Four-minute discrimination tests for Ss 11, 12, 13, 21, 22, and 23 conducted on 11 December 1964.

[b] Unweighted means.

Table 2

DISCRIMINATION OF VISUAL PROMPTING STIMULI[a]

Subjects' Previous Training	Subject Number	Total Number Responses	Percent Correct Responses	Mean Response Time (seconds)		
				All Responses	Error Responses	Correct Responses
Tactile Prompts (air jets)	1	216	96.3	0.73	0.59	0.73
	13	105	96.2	0.77	0.80	0.77
	23	91	93.4	1.16	1.30	1.15
	Mean for Group[b]		95.3	0.89	0.90	0.88
Visual Prompts (lights)	2	216	98.1	0.70	0.10	0.71
	12	99	97.0	0.77	1.07	0.76
	22	97	99.0	0.90	1.20	0.89
	Mean for Group[b]		98.0	0.79	0.79	0.79
Without Prompts (code sheets)	3	184	95.1	0.90	0.74	0.90
	11	101	95.0	0.86	0.90	0.85
	21	114	93.9	0.71	0.77	0.71
	Mean for Group[b]		94.7	0.82	0.80	0.82
Mean for All Subjects[b]			96.0	0.83	0.83	0.83
Standard Deviation for All Subjects			1.75	0.137	0.337	0.133

[a] Eight-minute discrimination tests for Ss 1, 2, and 3 conducted on 7 August 1964. Four-minute discrimination tests for Ss 11, 12, 13, 21, 22, and 23 conducted on 11 December 1964.

[b] Unweighted means.

Table 3

SUMMARY STATISTICS AND CORRELATIONS
FOR PROMPTING STIMULUS DISCRIMINATION TESTS[a]

	Tactile Stimuli	Visual Stimuli	Rank Correlations Between Prompting Stimuli
Mean Response Speed (seconds)	$\bar{X}$ = 1.78 σ = .514	$\bar{X}$ = .81 σ = .155	ρ = .823 P < .001
Over-all Response Accuracy (% correct)	$\bar{X}$ = 57.3 σ = 21.59	$\bar{X}$ = 96.2 σ = 3.41	ρ = .272 P > .10
Rank Correlations Between Speed and Accuracy Scores	ρ = .844 P < .001	ρ = .343 P < .10	

[a] Data from 9 Ss combined; N = 31 for these statistics (i.e., the number of different chord patterns). See Tables C-1 and C-2 for rankings of chords.

There appears to be a clear relationship between chord complexity and both response speed and accuracy--as more fingers are called upon to respond, both the accuracy and the speed of response decreases. [Table 3 shows the rank correlation between chord speed and chord accuracy for all subjects on the tactile stimulus discrimination tests (.844). The detailed tabulation showing the difficulty of the various chords is given in Table C-1 of Appendix C.]

Performance on the visual-stimulus discrimination tests was much less variable than that for the tactile stimulus, as shown in Table 2. (Performance for the 9 Ss combined appears in Table C-2 of Appendix C.) No subject failed to exceed 93 percent accuracy; accuracy scores ranged from 93.4 percent to 99.0 percent. Similarly, speed scores were closely grouped on the visual-stimulus discrimination tests, in contrast to the spread in speed scores for the tactile stimuli. Correlations among Ss on various discrimination test scores are shown in Table C-3 of Appendix C. The rank correlation between Ss' over-all response speed and accuracy was positive (rho = +.217), but as with the tactile stimulus discrimination tests, the magnitude of the relationship did not reach statistical significance.

The over-all high accuracy of responses to visual stimuli suggests that the variance in response accuracy and response speed in the visual-stimulus discrimination tests is due almost wholly to motor difficulties rather than to failure to perceive the chord response demanded by the stimulus pattern. Support for this view is provided by the low rank correlation (rho = .343) between response speed and accuracy for all subjects in the visual stimulus discrimination test (Table 3). Although response speed decreases in a fairly orderly fashion as chords increase in complexity and more fingers are called upon to respond, the over-all accuracy of responses to one-, two-, three-, four-, and five-finger chords is very nearly the same.

Comparisons of responses to certain individual chords in the two tests is revealing. For example, Chord 21 (the letter "U") calls for the thumb, middle finger, and little finger. On the tactile stimulus discrimination tests, this proved to be the single most difficult chord to make accurately. In contrast, no response errors were made to this chord pattern on the visual stimulus discrimination tests.

PERFORMANCE UNDER DIFFERENT TRAINING CONDITIONS

GENERAL. Three cycles of experiments were conducted to explore the effects of variations in training conditions upon the acquisition of skill in transmitting coded alphanumeric characters with the 5-key keyset. The pilot study, in which three Ss participated, extended over seven consecutive workdays during the period from 30 July through 7 August. This period served as a shakedown for the system and procedures and produced the first comparative performance data generated under operational conditions on this project.

The main experiment series was carried out between 14 September and 2 October. Six different Ss participated each week, or 18 Ss in all. During the first week, Ss were trained without automated prompting. Visual prompts were used during the second week, and the third week was spent training with the aid of tactile prompts.

The supplementary experimental cycle, between 7 and 11 December, involved six Ss--three who were new to the experiment and three who had participated in the main series. In the supplementary experiments, two questions were examined: (1) the effect of a response feedback signal upon performance, and (2) the proficiency limits that might be achieved with extended training wherein each S was permitted to modify practice conditions within certain limits.

RESULTS FROM THE PILOT STUDY. Two changes made the experimental setup somewhat different for this series than for the pretraining trials: (1) two independent keyset stations were operated simultaneously, thus permitting better utilization of the computer, and (2) a visual prompting keyset was constructed.

Three females unfamiliar with the experiment were recruited from among experienced typists at SRI. Subjects were assigned randomly to different training conditions--one to the tactile prompting keyset, one to the visual prompting keyset, and the "no-prompt" subject to either keyset, with the prompting mechanisms disconnected but with a code sheet available for reference. The training hour was broken into either 3- or 4-minute blocks; each S followed a schedule that provided 3- or 4-minute rest periods after each 6 or 8 minutes of practice time at the keyset.

On the first day of training, the primary stimulus (an alphanumeric character) and its associated prompting stimulus (either tactile or visual) were presented simultaneously to those Ss who received prompts. Beginning on the second day and continuing throughout the remaining 6 days of the series, an 0.8-second delay occurred between the presentation of the primary stimulus and its prompt. If a response was made within the 0.8-second period, no prompt was presented. No feedback signal of response accuracy was incorporated in the system at this time.

During the first 3 days of training, each S accumulated 80 minutes of practice time at her keyset. Commencing on the fourth day and continuing through the seventh day, a test period concluded each day's runs. During the test period, prompting stimulus mechanisms were disconnected so that only the primary stimulus was presented.

Table 4 summarizes the performance by days for all three Ss. Cumulative records for each individual S appear in Tables C-4, C-5, and C-6 of Appendix C.

Table 4

RESPONSE SPEED AND ACCURACY SCORES FOR SUBJECTS TRAINED FROM 30 JULY THROUGH 7 AUGUST 1964[a]

Day	Type of Score[b]	Training Conditions					
		Tactile Prompts		Visual Prompts		No Prompts	
		Practice Runs	Test Runs	Practice Runs	Test Runs	Practice Runs	Test Runs
1	Speed Accuracy	2.87 84.6%	-- --	1.05 98.4%	-- --	2.46 81.0%	-- --
2	Speed Accuracy	1.80 88.4%	-- --	0.98 94.3%	-- --	1.65 94.1%	-- --
3	Speed Accuracy	1.09 91.2%	-- --	0.84 98.8%	-- --	1.36 94.0%	-- --
4	Speed Accuracy	0.89 92.4%	0.79 91.5%	0.72 98.9%	0.68 99.6%	1.10 96.1%	1.03 95.2%
5	Speed Accuracy	0.70 95.9%	0.66 94.5%	0.64 97.4%	0.59 96.7%	1.01 92.4%	0.97 95.3%
6[c]	Speed Accuracy	-- --	-- --	-- --	-- --	-- --	-- --
7	Speed Accuracy	c c	0.58 97.2%	c c	0.60 98.5%	c c	0.77 96.4%

[a] One subject per training condition. More detailed individual records of performance for this period may be found in Tables C-4 through C-6 in Appendix C.

[b] Speed scores expressed as mean number of seconds for error responses and correct responses combined. Accuracy scores expressed as percent correct responses.

[c] Records of numbers of trials, response times, and response accuracy not available for all runs on the sixth day (6 August 1964) and for practice runs on the seventh day (7 August 1964).

As Table 4 indicates, all three Ss demonstrated increasing proficiency throughout the 7-day training period. By the end of the fourth day--the first day in which a test was conducted--each subject was approaching mastery of the code, and two of the three subjects had achieved over-all response speeds within the 0.8-second preprompt delay. The S trained with the visual prompting mechanism was the most consistent performer throughout the period; her record was the most accurate, and, compared to the other two Ss, her responses were faster. The greatest rate of improvement after the first day was shown by the S trained with the tactile prompting procedure. In the terminal test on the seventh day, she was the fastest performer and the second most accurate performer. The S trained without automated prompting showed consistent gains throughout the training period, but never achieved the same level of over-all proficiency that the other two Ss did.

The gap in the data on the sixth day and the first part of the seventh day resulted when a new analytical program, introduced on the sixth day, failed to extract an accurate record. From the orderly gains shown in Table 4, however, it would appear safe to interpolate for estimates of performance for this period.

During the last half of the seventh day, each subject participated in prompting-stimulus discrimination tests, as described earlier.

RESULTS FROM THE MAIN SERIES. The three-week series of experiments commencing 14 September and ending 2 October followed the general design established in the July-August pilot study.

Eighteen female Ss were recruited from outside SRI to participate in the experiment for one fixed hour (4-5 pm or 5-6 pm) through one week; three Ss participated each hour. All Ss were 18 years old or more, high school graduates or more, experienced touch-typists, and right-handed. Six Ss were randomly assigned to each of the following training groups:

(1) No automated prompting (Week 1). Subjects referred to code sheets during practice periods at the keyboard. Code sheets were removed during test runs.

(2) Automated visual prompting (Week 2). Subjects received visual prompts from a panel of five lights whose arrangement corresponded to the key positions of the keyset. Visual prompts were presented in conjunction with the appearance on the CRT face of the alphanumeric symbols of the 31-item code. The light panel was disconnected during test trials.

(3) Automated tactile prompting (Week 3). Subjects received only tactile prompts from air jets affixed to the five key positions. Tactile prompts were presented to Ss in conjunction with the appearance on the CRT of the alphanumeric code characters. The air-jet mechanism was disconnected during test periods.

The following modifications in the experimental arrangements were incorporated in this three-week series as a result of experience in the July-August pilot study:

(1) Conditions were not mixed during any one week or any trial session within a week. All Ss in each group received similar treatment.

(2) No explanation of the code was given nor was review or study of the code sheet permitted prior to any session, including the initial one. The no-prompt group (Week 1) was the only one that saw the code sheet, and these exposures were restricted to those times when Ss actually practiced at the keysets.

(3) One new tactile prompting keyset was constructed in which air jets were affixed directly to the keys rather than being mounted outside the keys adjacent to their tips. The Ss in the tactile-prompt group (Week 3) were rotated through both keysets so that their ability to discriminate prompts from both keysets could be compared (see Section V).

Two Ss worked simultaneously at separate, independent keysets while the third rested. Each had two consecutive 4-minute practice or test sessions followed by a 4-minute rest period. The work-rest pattern was varied daily to balance the position assignment of each S at the start of a day's runs.

Subjects were instructed to seek both speed and accuracy in performance. Commencing on the second day of each week, Ss were privately shown printouts of their own previous day's performance. No intergroup or intragroup comparisons were provided; Ss were simply told that they were "doing pretty well--just about as we expected." Subjects were encouraged to do their best, but care was taken to prevent overt individual or group competition.

For the visual-prompt group (Week 2) and the tactile-prompt group (Week 3), the following schedule was maintained in the time delay between the presentation of the alphanumeric characters and the prompting stimulus:

Day 1: Both primary and prompting stimuli were presented simultaneously.

Day 2: The prompting stimulus followed the primary stimulus by 0.5 second.

Days 3-5: The prompting stimulus followed the primary stimulus by 0.8 second.

Prompts were not presented during test trials.

By the conclusion of each 5-day training period, Ss in each group had spent the following amounts of time at a keyboard:

	Cumulative Time at Keyset (minutes)		
	Practice	Test	Total
No-prompt group	124	20	144
Visual-prompt group	120	24	144
Tactile-prompt group	128	24	152

An over-all summary of performance for all Ss under both practice and test conditions is shown in Table 5. As the data indicate, the performance of the three groups appears to be different, particularly under practice conditions, although mean performance under test conditions showed considerable similarity.

Table 5

RESPONSE SPEED AND ACCURACY SCORES FOR SUBJECTS TRAINED DURING THE PERIOD 14 SEPTEMBER THROUGH 2 OCTOBER 1964[a]

Day	Type of Score[b]	Training Conditions					
		Tactile Prompts		Visual Prompts		No Prompts	
		Practice Runs	Test Runs	Practice Runs	Test Runs	Practice Runs	Test Runs
1	Speed Accuracy	3.33 71.1%	-- --	1.36 91.2%	-- --	2.61 87.8%	-- --
2	Speed Accuracy	2.46 83.6%	-- --	1.07 93.8%	1.88 61.2%	1.76 94.0%	-- --
3	Speed Accuracy	1.82 86.8%	1.55 78.9%	1.26 93.6%	1.44 75.6%	1.48 94.0%	1.42 84.0%
4	Speed Accuracy	1.38 90.5%	1.14 85.3%	1.20 94.3%	1.39 83.3%	1.23 92.0%	1.22 83.3%
5	Speed Accuracy	1.10 90.9%	0.96 88.7%	1.08 95.9%	1.26 88.4%	1.14 90.4%	1.03 88.9%

[a] Six Ss per training condition. Training for each group lasted one week.

[b] Speed scores expressed as mean number of seconds for combined error responses and correct responses. Accuracy scores expressed as percent correct responses.

Test performance for all 18 Ss on the final day are shown in Table C-7 of Appendix C. To examine the extent to which differences were statistically significant, various tests were performed. First, mean differences between groups in both speed and accuracy on the 8-minute test on the fifth day were tested and none of the mean differences were statistically significant. Differences between groups in variability on final-day test performance were also tested. These results, shown in Table 6, indicate that the Ss of the tactile-prompt group were less variable in their response speeds than were Ss in the

Table 6

COMPARISON OF VARIABILITIES ON SPEED AND ACCURACY SCORES IN 8-MINUTE TEST AT END OF TRAINING[a]

Comparisons	Ratio of Variances of Mean Time of Correct Responses	Ratio of Variances of Mean Time of Total Responses	Ratio of Variances of Percent Correct Responses
No Prompts vs. Visual Prompts	$\frac{0.1949}{0.0485} = 4.02$ (P > .10)	$\frac{0.3848}{0.0768} = 5.01$ (P ≧ .10)	$\frac{155.6785}{32.1989} = 4.83$ (P > .10)
No Prompts vs. Tactile Prompts	$\frac{0.0485}{0.0086} = 5.64$ (P < .10)	$\frac{0.0768}{0.0158} = 4.86$ (P > .10)	$\frac{246.0749}{32.1989} = 7.64$ (P < .05)
Visual Prompts vs. Tactile Prompts	$\frac{0.1949}{0.0086} = 22.66$ (P < .01)	$\frac{0.3848}{0.0158} = 24.36$ (P < .01)	$\frac{246.0749}{155.6785} = 1.58$ (P > .50)

[a] Variances calculated from standard deviations reported in Table C-7 according to the relationship $s^2 = (N/N-1)\sigma^2$. All probabilities are for two-tailed tests.

other two groups; in particular, they were more homogeneous in response speed than the visual-prompt group. In contrast, the tactile-prompt group showed the greatest dispersion in accuracy scores.

Three analysis-of-variance tests were performed following the model suggested by McNemar (1955, pp. 332-335) for a pseudo three-way classification (subjects by methods by days). The first analysis, summarized in Table 7, examined response speed under practice conditions over the five-day period for the three groups. The data support the impression, gained from the summary data in Table 5, of differences between groups, differences over time, and different rates of change over time within groups.

Table 7

ANALYSIS OF VARIANCE FOR RESPONSE SPEED IN PRACTICE CONDITIONS[a]

Source of Variation	Sum of Squares	df	Mean Square	F	P
Individuals	4.48	15	0.299	--	
Training Methods (M)	10.47	2	5.235	17.51	< .001
Days (D)	17.56	4	4.390	12.33	< .001
Interaction: M X D	8.26	8	1.032	2.90	< .01
Remainder	21.39	60	0.356	--	
Total	62.16	89			

[a] Based on performance summarized in Table 5.

The second analysis of variance considered response speed for each group under test conditions over the final three days (i.e., those days during which each group was tested). Table 8 shows the three groups to be substantially similar to one another in their performance under test conditions. The only variance ratio approaching statistical significance was that for "days."

The third analysis of variance, summarized in Table 9, was applied to response-accuracy scores under test conditions for the three groups; no significant variance ratios were obtained.

Table 8

ANALYSIS OF VARIANCE FOR RESPONSE SPEED IN TEST CONDITIONS[a]

Source of Variation	Sum of Squares	df	Mean Square	F	P
Individuals	2.92	15	0.195	--	
Training Methods (M)	0.25	2	0.125	0.64	NS
Days (D)	1.36	2	0.680	2.27	< .20
Interaction: M X D	0.31	4	0.078	0.26	NS
Remainder	9.01	30	0.300	--	
Total	13.85	53			

[a] Based on performance summarized in Table 5.

Table 9

ANALYSIS OF VARIANCE FOR RESPONSE ACCURACY IN TEST CONDITIONS[a]

Source of Variation	Sum of Squares	df	Mean Square	F	P
Individuals	3,335.68	15	222.38	--	
Training Methods (M)	81.19	2	40.60	0.18	NS
Days (D)	753.64	2	376.82	1.36	NS
Interaction: M X D	145.31	4	36.33	0.13	NS
Remainder	8,310.65	30	277.02	--	
Total	12,626.47	53			

[a] Based on performance summarized in Table 5.

RESULTS FROM THE SUPPLEMENTAL SERIES

Effects of Feedback on Skill Acquisition. Following the completion of the main series of experiments, the control program was modified to provide a feedback signal to Ss immediately following each response. The feedback program directed the alphanumeric character corresponding to the chord response to appear in the scope directly below the stimulus character. This signal remained visible for 0.5 second, after which time both the primary stimulus character and the feedback character were extinguished. Comparison of the feedback character with the primary stimulus indicated to the Ss whether the chord formed in response to the primary stimulus was appropriate.

To examine the effects of continuous and immediate response feedback upon learning rate, three new Ss were recruited to undertake training for a five-day period. These Ss were comparable in general background to those previously employed. Training conditions were similar to those followed during the main series, except that the key-set rotation schedule used in the pilot study was followed. Ss were randomly assigned to a training condition--automated tactile prompting with feedback, automated visual prompting with feedback, or no automated prompting (i.e., code sheet memorization) but with feedback.

Table C-8 presents a combined record for the three Ss over the 5-day period. Individual records for the three Ss are shown in Tables C-9 through C-11 in Appendix C. The three Ss were essentially identical in both response speed and accuracy by the final 4-minute test session on the fifth day--by that point, over-all mean response times were between 0.75 second and 0.78 second, and response accuracy scores between 96.7 percent and 99.1 percent for the three Ss.

No statistical tests comparing the three Ss with one another seem appropriate nor, for that matter, necessary. It is meaningful, however, to contrast the performance of the three Ss who received continuous response feedback with the performance of the 18 Ss trained under similar prompting conditions but without response feedback. Figure 2 compares the mean test performance for both the Ss trained with and without a response feedback signal. More detailed summaries for both groups appear in Table C-8 and C-12 of Appendix C. (See Table 5 for the records of each training group.)

Tables C-8 and C-12 show rather clearly that the three feedback-trained Ss compared favorably with the most proficient of the 18 Ss trained without feedback. Differences between the two groups favor the feedback-trained group at most points of possible comparison.

A statistical test of differences between the feedback-trained group and the nonfeedback-trained group was performed for terminal test performance on the fifth or final day of training. To increase the reliability of the performance measures for the feedback-trained group, the two 4-minute tests administered on the fifth day were combined. The statistical tests apply, therefore, to performance tests of 8 minutes duration administered to both groups at the end of essentially identical amounts of total training time. The summary statistics and the test of mean differences are presented in Table 10.

The very small size of the feedback-trained group suggests restraint in interpreting the statistical significance of the feedback group's superiority in response accuracy. The difference is in the expected direction, however, and the magnitude of the t-ratio provides persuasive support for the conclusion that continuous and immediate response feedback does, facilitate psychomotor learning.

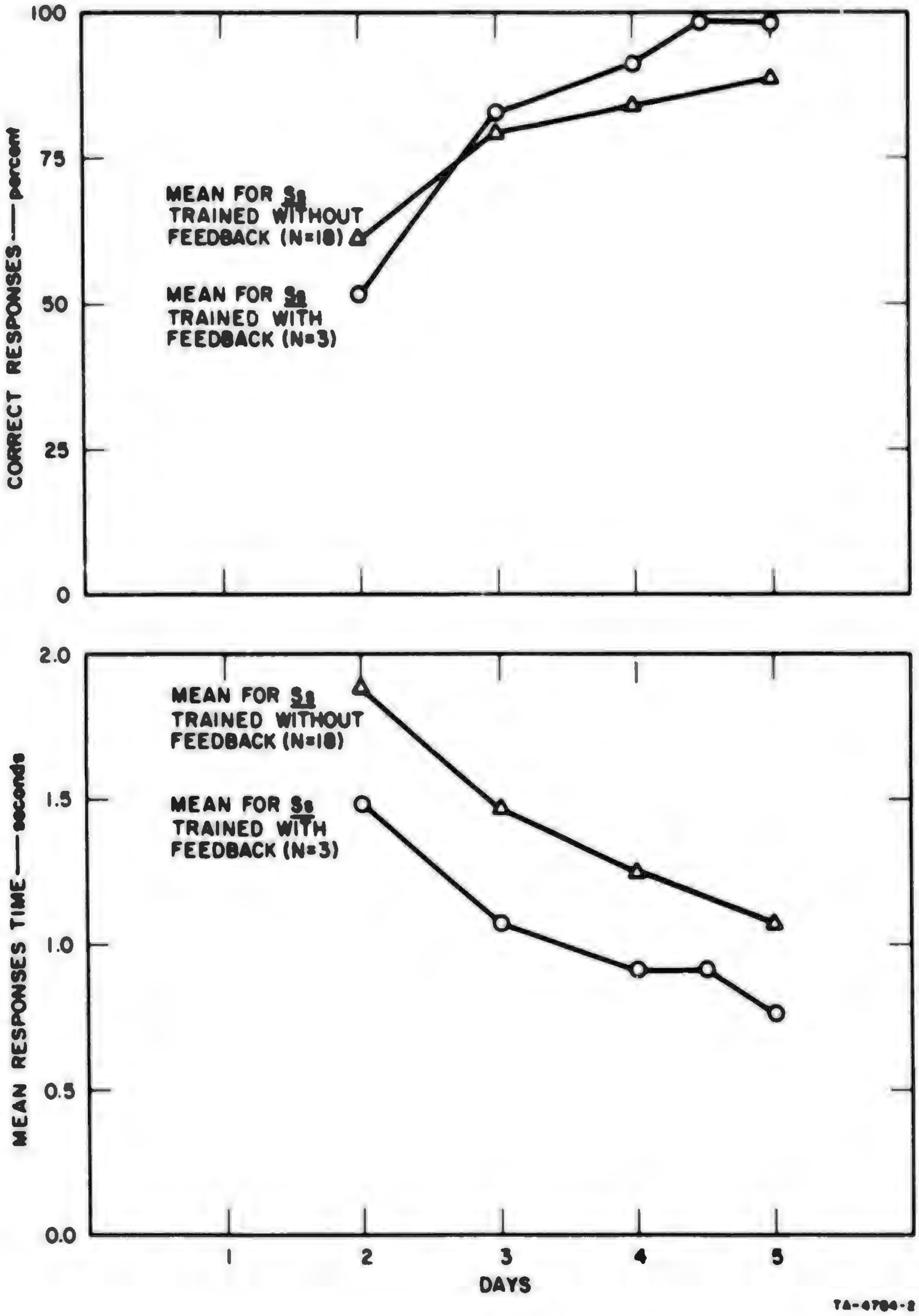

FIG. 2 MEAN TEST PERFORMANCE OF SUBJECTS TRAINED WITH AND WITHOUT FEEDBACK

Table 10

MEAN DIFFERENCES IN SPEED AND ACCURACY ON EIGHT-MINUTE TERMINAL TESTS OF PERFORMANCE BY FEEDBACK-TRAINED AND NONFEEDBACK-TRAINED GROUPS

	Nonfeedback Trained (N = 18)	Feedback Trained (N = 3)
Mean Total Response Time (sec)	1.08	0.84
Standard Deviation	0.387	0.045
Mean Difference	0.24	
t[a]	1.021 ($P > .10$)	
Percent Correct Responses	88.65	98.53
Standard Deviation	10.98	0.695
Mean Difference	9.88	
t[a]	36.296 ($P < .001$)	

[a] $$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s^2}{N_1} + \frac{s^2}{N_2}}} \quad \text{where } s^2 = \frac{\Sigma x_1^2 + \Sigma x_2^2}{N_1 + N_2 - 2}$$

$$\text{and } \Sigma x^2 = \frac{1}{N}\left[N\Sigma X^2 - (\Sigma X)^2 \right]$$

Estimates of Proficiency Limits. Three Ss who had participated in the main series were recalled for further training during the period 7-11 December. They were among the better performers from the earlier experiment and may be identified in Table C-7 as subjects C, K, and O.

These Ss were urged to work toward maximum response speed consistent with accuracy. To accelerate their relearning of the code, each was allowed to study the code sheet and to use it for reference during practice sessions if desired. Relearning of the code was fairly rapid. Within 20 minutes of review practice, each S had returned to a level of response accuracy very similar to that achieved at the end of her training 8 to 10 weeks earlier. After about 30 minutes of review practice and testing, each S was also responding at about the same speed as she had achieved by the end of her earlier training. Cumulative records for each of these Ss covering both weeks of training are shown in Appendix C (see Tables C-13 through C-15).

On the basis of the three-subject pilot study conducted in July-August, where training had extended over a 7-day period, it had appeared reasonable to expect that over-all mean response times of 0.50 second or less would be achieved by one or more of the Ss in this retraining experiment. Two of the three Ss in the pilot study, it will be recalled, had achieved over-all mean response times below 0.60 second during test runs toward the end of their training period. These performances were never matched by any subsequent Ss, including the three who received the second week of training. Undoubtedly the 8-10 week recess between the end of one training session and the start of another was a substantial handicap for them to overcome. Nevertheless, the rate of improvement in response speed shown during the final days of training was not as great as had been anticipated.

The cumulative performance of these three Ss over all their test runs--three or four during their first week of training and 10 during their second week of retraining--is shown in Figs. 3, 4, and 5. Fluctuations in response accuracy as increased speed was sought suggest that a reasonable upper limit for transmitting the 31-item code on such 5-key keysets as were used in these experiments probably falls in the range from 0.50 to 0.60 second for all chords.

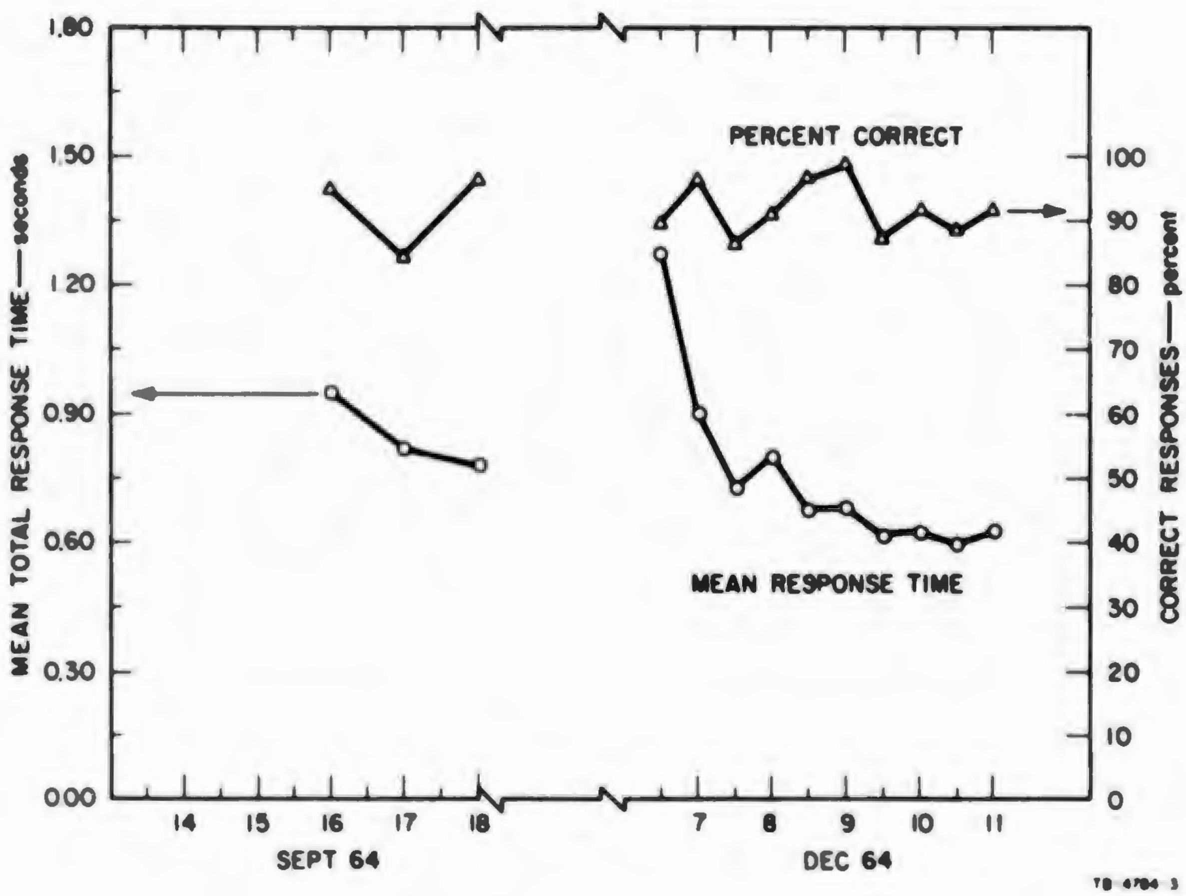

FIG. 3 TEST PERFORMANCE OF "NO PROMPT" SUBJECT

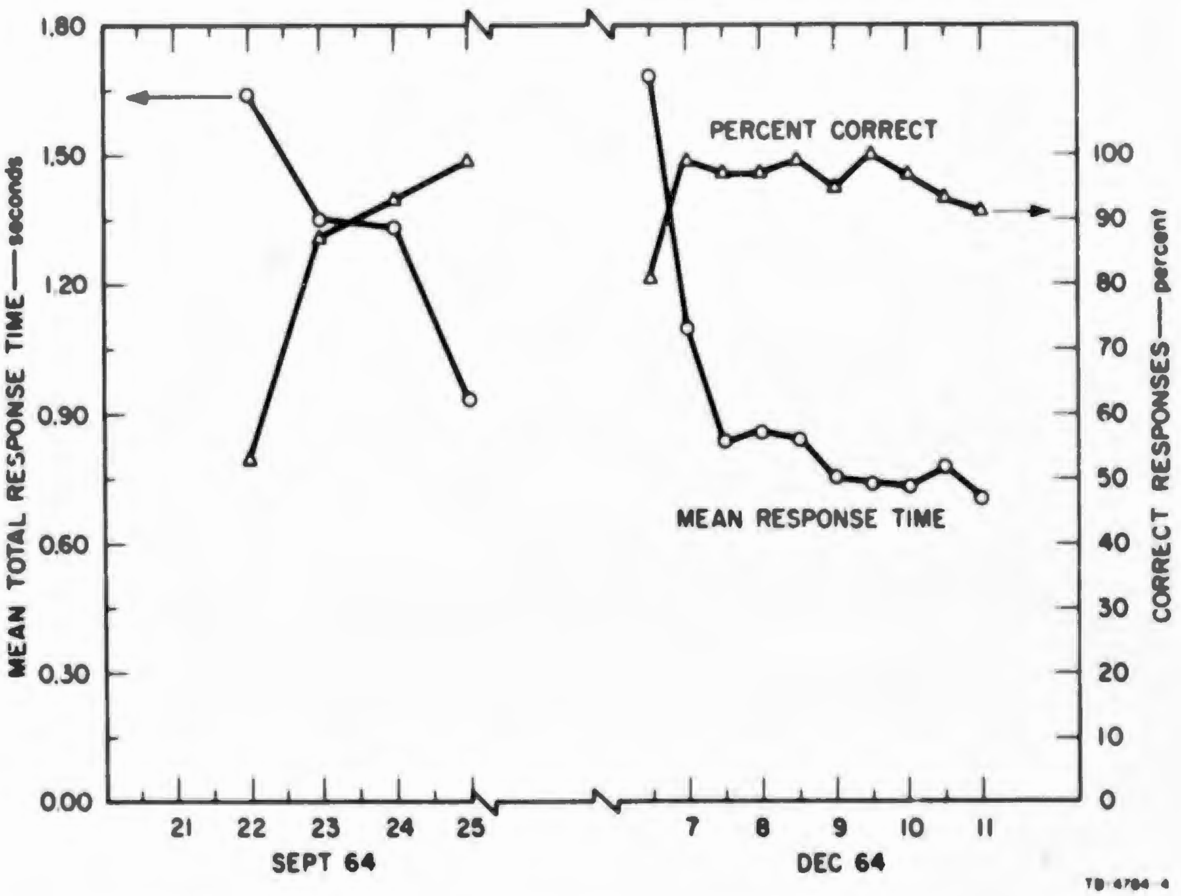

FIG. 4 TEST PERFORMANCE OF "VISUAL PROMPT" SUBJECT

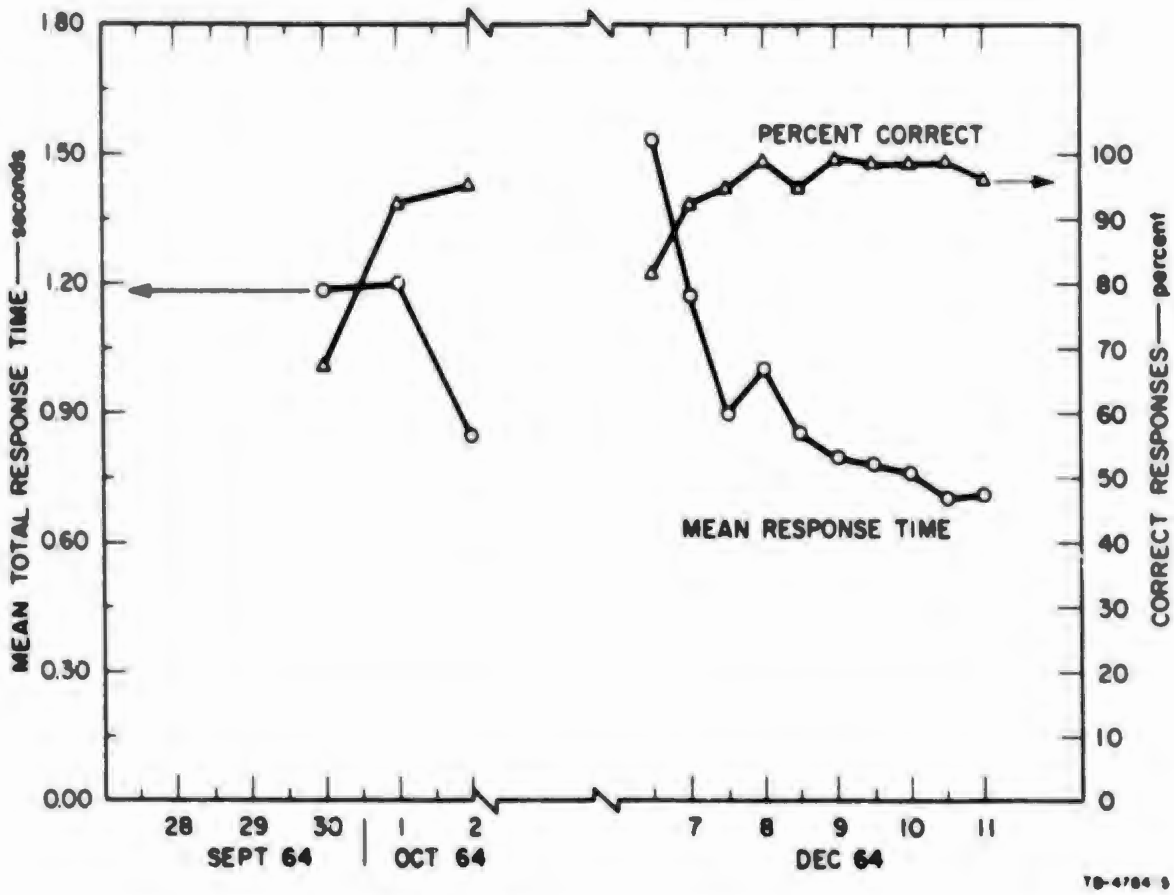

FIG. 5 TEST PERFORMANCE OF "TACTILE PROMPT" SUBJECT

SECTION V

DISCUSSION

DISCRIMINATION OF PROMPTING STIMULI

Response prompting by tactually stimulating the fingers with air jets, as employed in this study, is much more difficult to discriminate accurately than is response prompting with visual signals. Large differences obtained among Ss in the accuracy with which they could discriminate tactile prompts and the speed with which they were able to respond to them (see Table 1). In contrast, Ss were closely grouped in both response accuracy and response speed in the visual stimulus discrimination test (see Table 2).

Ability to discriminate tactile stimuli of the kind used in this study improved with practice, but ability differences among Ss are likely to be great at the time of their initial exposure to tactile stimuli, and may become even greater following similar periods of practice, as data in Table 1 suggest.

Findings regarding the relative difficulty of the 31 chord patterns correspond fairly closely to results reported by others when chord difficulty is defined in terms of speed of response. Data from this study and from other studies are not so similar when chord difficulty is defined in terms of accuracy of response.

The visual stimulus discrimination test (see Tables 2, 3, and C-2) provide data that can be compared with findings reported by Ratz and Ritchie (1961), and by Seibel (1961). Ratz and Ritchie studied operator performance on a chord keyboard in response to visual presentations of the desired chord patterns; their apparatus was comparable to that used at SRI, although it differed in many respects. Further, the performance problem they posed to subjects apparently resembled that posed to subjects in the SRI study. Ratz and Ritchie reported a median response time for all chords of 1.16 seconds, which is substantially greater than 0.78 second (mean response time for the 16th ranked chord) found in the SRI study. Their ranking of chord difficulty according to response time corresponds closely to that developed here; the rank correlation between the Ratz and Ritchie findings and the response time ranking of the SRI study is .928.

Seibel also studied performance on a 5-key chord keyboard in a testing situation similar to that used by Ratz and Ritchie. Seibel takes issue with Ratz and Ritchie's conclusions regarding asymptotic performance after as little as two days' training, and shows response times improving even up to 11,000 trials. In contrast to Ratz and Ritchie, Seibel reported "discrimination reaction times" between 0.30 and 0.35 second for the average of all 31 chords--some three times as fast as Ratz and Ritchie, and twice as fast as the SRI study. Nevertheless, Seibel's ranking of chord difficulty determined by mean reaction times of four highly trained subjects correlated .896 with Ratz and Ritchie's ranking and .889 with the SRI ranking.

The response times reported by Ratz and Ritchie and by Seibel are less variable than those obtained in this SRI study. Response time variability in the three studies, expressed as ratios of minimum and maximum response times to the median response time, was as follows:

	Ratz and Ritchie	Seibel	SRI
Minimum time/Median time	0.88	0.89	0.76
Maximum time/Median time	1.27	1.11	1.48

The reasons for such large differences in over-all response times are not clear. Seibel's Ss were the most practiced and Ratz and Ritchie's were the least practiced. Seibel eliminated from his analyses both error responses and responses deviating more than three sigmas from the mean of the remaining distribution; these omissions would depress the mean reaction time slightly. Instructions to Ss in both the Ratz and Ritchie study and the Seibel study are not reported explicitly. Since Seibel reports a rank correlation of .836 between "discrimination reaction time" and errors, it seems likely that his Ss were instructed to minimize reaction time.

The correlation reported by Seibel between reaction time and errors (.836) is much larger than that obtained in this study. As Table 3 indicates, the correlation between chord rankings on speed and accuracy on the visual stimulus discrimination test in this study was only .343. The rank correlation between Seibel's accuracy ranking of chords and the accuracy ranking reported here is only .263, as might be expected from the different relationships found in the two studies between response speed and accuracy. One reason for these discrepant correlations undoubtedly lies in differences between the two sets of data in error scores. Seibel reports an over-all error rate of 9.9 percent in contrast to 3.8 percent in the present study (see Table 3). The narrower range of error scores in this study would attenuate somewhat any correlation between response accuracy and response speed.

Data from the present study, when compared, in particular, to those of Seibel, suggest that response accuracy and response speed are not only sensitive to amount of practice but also to the "response set" induced in Ss by the instructions prior to the test run. Seibel's Ss apparently concentrated on speed of response as suggested by the fairly high over-all error rate (9.9 percent) among Ss with considerable prior practice. In the present study, Ss were encouraged to seek speed consistent with accuracy--a response set quite consistent with tests of typing skill, for example, with which these Ss were all familiar. It is reasonable to hypothesize that Ss in the present study would have shown different performance had they been specifically instructed to minimize response time and to discount errors. Given such instructions, one would anticipate (1) an error rate somewhat greater than the 3.8 percent obtained in the visual stimulus discrimination test, and (2) an over-all response time somewhat faster than that demonstrated.

No data directly comparable to the results of the tactile stimulus discrimination test have been found in other sources. Comparison of the tactile stimulus discrimination test to the visual stimulus discrimination test, however, suggests an approach to the problem of sorting out response errors and decrements in response speed that are due to lack of motor skill in contrast to those due to difficulties in perceiving the stimuli.

Relationships of particular interest are probably best summarized by the correlations between chord ranks shown in Table 3 and among Ss shown in Table C-3 of Appendix C. From these data it can be seen that relative chord difficulty, as measured by mean response time over all Ss, is not markedly different for chord responses made to visual stimuli and to tactile stimuli; the correlation of .823 between speed rankings of chords from the tactile test and the visual test indicates this. The low correlation (.272) between accuracy rankings from the two tests suggests that most of the difficulties experienced by Ss on the tactile test were in discriminating the tactile stimuli rather than in making the motor responses. The low correlation (.343) between over-all speed and accuracy rankings on the visual test reflects the general ease with which even complex chord patterns were discriminated in the visual test. The high correlation (.844) between speed and accuracy rankings on the tactile test suggests that simple chords are both most accurately discriminated and most easily responded to.

A couple of apparently anomalous relationships appear when correlations between rankings of Ss on the two discrimination tests are compared to the correlations between rankings of chords shown in Table 3. As noted above, a high positive correlation (.844) obtained between speed and accuracy ranks of chords over all Ss in the tactile stimulus discrimination test (Table 3). When individual over-all speed and accuracy scores on the tactile stimulus discrimination test are correlated, however, the relationship is very low and negative (-.200). Considered together, these two correlations indicate that (1) the most easily discriminated chord patterns are also the ones most quickly responded to, and (2) the best strategy for an individual to follow in improving the accuracy with which he discriminates tactile stimuli is to reduce his speed of response. All Ss adopted this strategy to some extent, and some adopted it to a radical degree; the correlation between Ss on speed scores on both discrimination tests was .450. The correlation between rankings of chord speed on both tests, however, was substantially higher than this, at .823 (see Table 3), thus indicating that a chord's relative position in a speed-of-response scale over many Ss remained fairly stable regardless of the test-taking response style adopted by the subject.

EFFECTS OF KEYSET DESIGN ON DISCRIMINATION OF CUES

As a result of the discrimination test conducted on 7 August and verbal reports from Ss regarding difficulties in perceiving tactile cues, a second tactile prompt (air-jet) keyset was constructed. In this keyset, the air-jet nozzles were mounted in the keys rather than outside the tips of the keys. It was hoped that this modification would reduce the ambiguity with which cueing signals were perceived, since the air jets seemed to be better localized and the flow of air through each key-mounted nozzle created a slight but perceptible vibration in each key.

During the week of 28 September through 2 October, six Ss who were trained with the aid of tactile prompting techniques alternated during each session between the old keyset with the external air jet and the new keyset with the internal airjet (see Table C-16 in Appendix C). All six Ss performed slightly faster on the old keyset, although the practical differences in speed were very slight by the fourth or fifth day of practice. A somewhat lighter "touch" on the old keyset probably contributed to this difference. This difference in touch also may have served to obscure somewhat any actual differences between the keysets in cue discriminability. It was evident that for these Ss, the new keyset was not an improvement in terms of speed. Four of the six were more accurate when using the new keyset, but the practical difference in accuracy was trivial, suggesting that neither keyset was superior to the other.

GENERAL LIMITATIONS OF THE DATA

Three instances of difficulty were experienced in the recording of data. The first occurred during the pilot study, when an incompletely tested analytical program was found to contain an error, and data for 28 minutes of practice runs and 4 minutes of test runs for three Ss were omitted from the cumulative record. The second difficulty was an experimenter error that occurred on the first day of the main series, and resulted in the loss of 8 minutes of practice data for one S. The third occurred during the second day of the third week of the main series, when a paper tape failed to feed properly and 12 minutes of practice data for two Ss were lost.

A question remains regarding the extent to which findings on the discrimination of tactile stimuli and on response speed are equipment-bound. These findings are vulnerable to the influence of keyset design. One might suppose that keysets with somewhat different key shapes and arrangements would have been easier for all Ss to operate, thus leading, perhaps, to somewhat different error rates and response times. A glove-like contrivance, for instance, might have permitted better "targeting" of the airjets. Since no changes were made in the basic design of the keysets used by all Ss during the experiment, however, the relative performance of the different training groups probably can be considered as stable findings.

The degree to which discrimination of tactile prompts was influenced by the particular equipment used also limits somewhat the generalization of conclusions regarding the utility of tactile prompts. Recall that the group trained with the aid of tactile prompting was significantly less variable in response speed than the group trained by the visual prompting method. It is tempting to ignore, for purposes of speculation, the physical characteristics of the tactile prompts and to consider them as a special case of what might be called "proximal" prompts--that is, prompts directed toward and received by the musculature required to execute a motor act. (Thus, proximal prompts for a finger response on a 5-key keyset could be any appropriate signal directed to the fingers--a mechanical linkage, a mild shock, a vibration, pressure, etc.). Conceivably, techniques for providing proximal prompts could be developed that are less ambiguous and more easily discriminated than were the tactile air-jet signals used in this study. If difficulties in discrimination could be at least partly overcome, then the usefulness of proximal prompting in learning certain sensorimotor skills might be markedly increased. This would be particularly true if the decrease in intragroup variability proved to be reproducible for other Ss and for other types of sensorimotor skill learning.

Transfer of the skills of encoding the 31 alphanumeric characters (i.e., by striking appropriate chords) from a simple paired-associate recognition test to the transmission of sequences of textual material was not examined. In keeping with generally accepted learning principles, it probably would be desirable to gradually enlarge the stimulus from single characters to groups of 2, 3, 4, and 5 or more characters so that Ss could, after mastering the basic code, learn the higher-order skills involved in forming sequences of chords. Criterion tests appropriate to such training materials (e.g., sequences of character groups, nonsense syllables, or plain language text) could also be introduced. If a binary-coded chord keyboard were seriously considered for communication, then transmission problems closer to those expected in an operational setting would need to be incorporated in the training regimen.

Reception of visually or tactually coded information and translation into alphanumeric characters was not examined at all in the present study. If analogies from other code-learning tasks (e.g., Morse code) are appropriate, then one would expect that proficiency in receiving would be more difficult to achieve than proficiency in transmitting. The question of the optimum sequencing and alternation of transmission and receiving training could also be raised for a code system of the type examined in this study.

SECTION VI

SUMMARY AND CONCLUSIONS

The primary aim of the study was to explore the effectiveness and feasibility of automating sensorimotor skill training. The general hypothesis was that automatically presented response prompts would aid the development of the skills required to operate a 5-key chord keyboard for transmitting binary coded alphanumeric characters. The following conclusions can be drawn from the results of the study.

(1) Automating sensorimotor skill training appears to be wholly feasible. Whether or not automating skill training is justified by promise of increased training effectiveness or greater training economy will depend upon the nature of the skills to be learned and the characteristics of the trainees. For the skill learning task examined in this study, for example, automating the prompting procedure did not increase the over-all rate at which the skill was acquired or raise the level of proficiency ultimately achieved. But a computer-served trainer such as that developed for this study (including associated programs and display, control, response, and monitoring equipment) will provide accurate and continuous control of training conditions and complete records of individual performance for a number of trainees performing simultaneously. Considering the flexibility that a computer-served system can achieve through alterations in its display and control procedures, the utility of such a system for a general purpose skill-training research laboratory appears great.

(2) The two automated prompting techniques examined in this study--tactile prompts and visual prompts--had little discernible effect on eventual keyboard operating skill as measured by terminal tests of response speed and accuracy. Subjects trained without the support of automated prompts (i.e., those Ss who memorized the code by referring to code sheets during practice sessions) performed essentially as well in terminal tests of performance as did Ss trained with the support of either automatic visual or tactile prompts.

Learning under the tactile prompting condition led to somewhat less variability in response speed within the group so trained; this same group, however, showed greater variability than other groups on response accuracy, due to the difficulty most Ss experienced in discriminating the tactile cues. The tactile prompting technique actually appeared to inhibit code learning for some Ss. For Ss unable to discriminate the prompts accurately, full learning of the code was impossible in the absence of a response feedback signal. For Ss who were able to discriminate the tactile cues, either from the outset of training or subsequently as a result of experience, the tactile prompting technique proved to be as effective as the more quickly and more universally discriminated visual cues. Considering only those Ss who were able to discriminate the tactile prompts, the tactile cueing technique led to learning at least as effective (and perhaps somewhat more effective) than that shown in terminal test performance by Ss trained under different conditions.

(3) Developing response accuracy was materially aided by the presence of a response feedback signal to indicate to Ss whether or not their responses during practice sessions were correct. Ss trained under conditions that included a feedback signal performed more accurately than Ss trained without the aid of response feedback. This result obtained regardless of other characteristics of the training situation, such as the presence or absence of automated response prompts.

(4) The learning problem presented to all Ss appeared to be too simple to provide an adequate test of differences in training techniques. Most Ss learned the code fairly quickly under all training conditions. Once the code was mastered, increases in response speed appeared to be primarily a function of additional practice. Discriminable prompts, in other words, appeared to make learning of the cognitive aspects of the problem task somewhat easier but were not noticeably helpful in increasing response speed. If response prompts are to be used to aid the learning of motor acts, then serial motor acts of greater complexity than forming and striking a chord on a 5-key keyboard probably should constitute the learning task.

SECTION VII

RECOMMENDATIONS

The following recommendations are based on the foregoing conclusions.

(1) Cost/benefit analyses of alternative training procedures should include the possibility of a computer-served automated system whenever a requirement for skill training is generated. Automating training for many sensorimotor skills is feasible. With growing experience in the uses of such systems, it is plausible to expect that training system analyses will show increasingly that the benefits of such systems for specific training applications and general training research will justify the costs associated with their development, refinement, and use.

Particular encouragement should be given to investigations of procedures for automatic and continuous on-line analyses of learner performance so that the training system can adapt to changing learner requirements. If a training system is to adapt appropriately to the cumulative performance of individual trainees, then psychologically defensible rules must be programmed to guide these adaptive changes. Research leading specifically to the development of such rules and programs appropriate to them should be stimulated.

(2) When the nature of a training problem is such that response prompting techniques suggest means for facilitating skill acquisition, particular care should be taken to assure that the prompting stimuli under consideration will be discriminated easily by all trainees, either from the outset or with a minimum of special discrimination training. In general, more familiar stimuli are to be preferred over less familiar or exotic stimuli as response cues so long as the training problem permits their use. When consonant with the response patterns to be learned, visual and aural stimuli probably should be preferred over tactile, kinesthetic, or other stimuli. Exceptions may occur in situations where normal channels are unavailable or overloaded, or when unusual stimuli are more compatible with the kinds likely to be encountered in operational settings. For example, if a response in an operational environment is to be triggered by visual signals, then visual stimuli probably also offer the best option as response-prompting stimuli.

If response prompts for motor acts have utility, such utility appears likely to be greatest for sequences of motor acts in which (1) the precise order of acts must be mastered and (2) each successive act does not embody sufficient cues to unambiguously prompt the next appropriate act. Training operators of certain types of control consoles illustrates an area where the utility of response prompts is not self-evident and probably requires specific investigation.

(3) Further study should be encouraged of the utility of proximal prompts (i.e., prompting stimuli directed toward the musculature required to execute a motor act or sequence of acts) as a means for figuratively, if not literally, "short-circuiting longer neural pathways. Evidence from the present study suggests that tactile prompts directed to the fingers led to less variable performance in chord-striking response speed than did visually mediated prompts for stimulating the same response pattern. An explanation for this was not developed in the present study, nor is it at all certain that the findings would be reproduced with different samples of Ss, different types of prompts, and different responses.

(4) Means for providing response feedback signals should be incorporated in all training system designs; if not incorporated, compelling evidence should exist to justify their exclusion. Response feedback materially aids Ss in the acquisition of the cognitive components of a perceptual-motor act (e.g., in the present study, in learning the associations between alphanumeric symbols and chord patterns).

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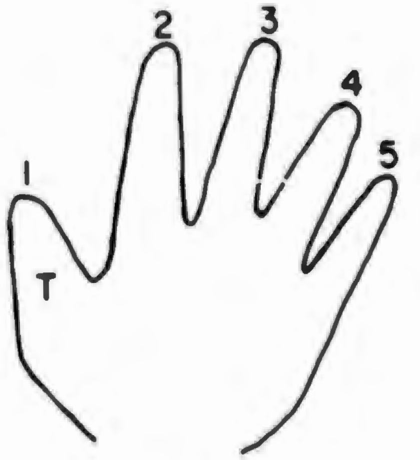
Appendix A

BINARY ALPHANUMERIC CODE



Chord 1	A	1				
Chord 2	B		2			
Chord 3	C	1	2			
Chord 4	D			3		
Chord 5	E	1		3		
Chord 6	F		2	3		
Chord 7	G	1	2	3		
Chord 8	H				4	
Chord 9	I	1			4	
Chord 10	J		2		4	
Chord 11	K	1	2		4	
Chord 12	L			3	4	
Chord 13	M	1		3	4	
Chord 14	N		2	3	4	
Chord 15	O	1	2	3	4	
Chord 16	P					5
Chord 17	Q	1				5
Chord 18	R		2			5
Chord 19	S	1	2			5
Chord 20	T			3		5
Chord 21	U	1		3		5
Chord 22	V		2	3		5
Chord 23	W	1	2	3		5
Chord 24	X				4	5
Chord 25	Y	1			4	5

Chord 26	2		2		4	5
Chord 27	3	1	2		4	5
Chord 28	4			3	4	5
Chord 29	5	1		3	4	5
Chord 30	6		2	3	4	5
Chord 31	7	1	2	3	4	5

Appendix B

OPERATING PROCEDURES AND EQUIPMENT

OPERATING SYSTEM

Two Ss are seated before the two display-response stations, and the experimenter (also referred to as the "operator") controls the experiment from the computer console, as shown in Fig. B-1.

For each of the two Ss, the operating cycle during an experimental run is as follows: A character (representing the primary stimulus) is presented on the display screen to the S at time t0. The S responds by striking the chord on the keyset that corresponds to the primary-stimulus character. The computer keeps track of how the S manipulates the keyset. After t0, the first key closure signals the start of the response, and the subsequent all-keys-up state signals the end of the response action. The response chord is taken to be the accumulation of all keys closed during this response interval.

Response time is measured, in 120ths of a second, between t0 and the closure of the final key in the response chord. If the response action is not terminated (by opening all the keys) within the given number, TC, of tenths of a second, the cueing (prompting) stimulus is presented. A light pattern flashes on, as shown in Fig. B-2, or a pulsating air jet is applied to the fingers--with a pulsation rate as set by the operator at the start of the experimental run.

When all keys are released, at the end of the response action, the computer punches a series of data frames on the paper-tape output, containing:

The ID number of the S
The identity of the station to which S is assigned
The chord pattern corresponding to the primary stimulus
The chord pattern given as response by the subject
The response time, in 120ths of a second.

The computer then automatically generates the next primary stimulus to be presented. There is a number, TD, set by the operator for a given experiment, and after a wait of TD tenths of a second (from the all-keys-up instant), the computer presents this next primary stimulus to the S to start the next stimulus-response cycle. A cyclic sequence of these primary-stimulus patterns is repeated; the cycle is 31 x 32 patterns in length, and is generated by an algorithm from the preceding pattern. The relationship between successive patterns is too complex to be detectable by a human, and the total cycle length seems long enough that Ss do not remember it.

Internal data accumulation for each S takes place in the computer memory during each run. The accumulated data are integrated, and may be typed or punched out by the operator. Two matrices are kept for each S, with the rows corresponding to stimuli patterns and columns corresponding to response patterns given to those stimuli. After each stimulus-response cycle, these matrices are updated appropriately. In the response

FIG. B-1 TRAINING AND TESTING SETUP

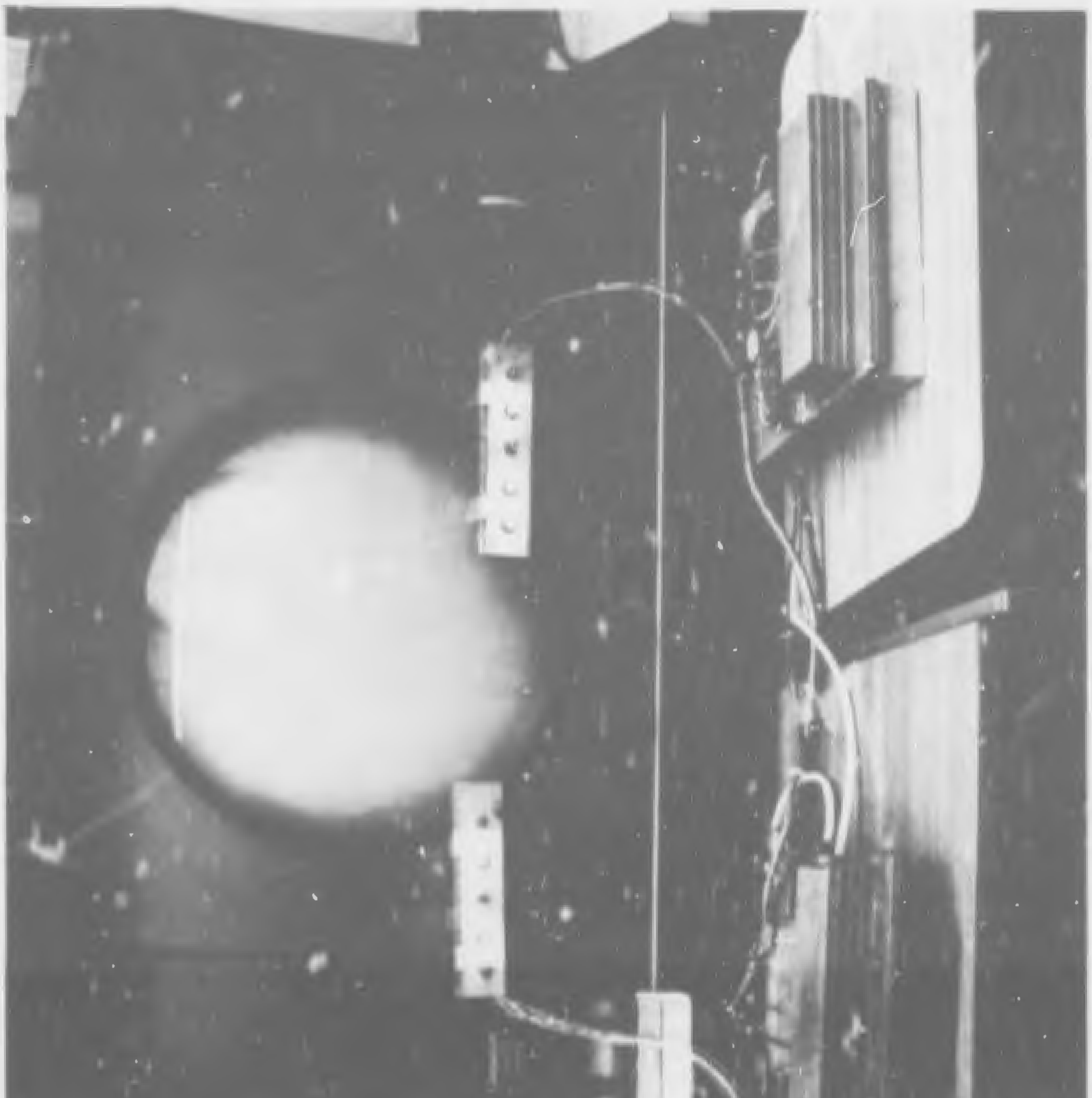


FIG. B-2 CRT DISPLAY, KEYBOARDS, AND VISUAL PROMPT SIGNALS matrix, the value ONE is added to the matrix element corresponding to the stimulus and response patterns given. In the time matrix, the response time, in tenths of a second, is added into the cell corresponding to the stimulus and response patterns given.

The operator usually stops the computer at the end of 4 minutes to change Ss, according to the schedule. An alarm clock feature has been programmed so that the computer automatically stops. When a new S is introduced, the only parameters that need be changed are the ID numbers of the Ss associated with the assigned stations.

EQUIPMENT

The 160A computer used in these experiments is desk-sized, as can be seen from Fig. B-3 (where the computer is in the foreground) and Fig. B-1 (where the console is being attended by the experimenter-operator). The computer accommodates 12-bit words, has a 6.5-μsec cycle time, and has an 8,000-word core memory.

There are two input/output channels, to which external electronic equipment can be directly coupled. One of these channels is buffered, so that data can be sent out or received while the computer is executing an

FIG. B-3 OVER-ALL LAYOUT, SHOWING COMPUTER, CRT DISPLAY, KEYBOARDS AND SYMBOL GENERATOR independent set of program instructions. There are also two external connections upon which inputs cause any ongoing program to be interrupted and a corresponding special program to be initiated (the special program usually restarts the interrupted program when through with its special task).

Input and output are on paper tape. The paper-tape reader can be seen on top of the computer work area, at the left in Fig. B-3 and at the far right in Fig. B-1. The paper-tape punching mechanism is buried inside the computer, to the left of the operator, and spews tape out that end.

Normal auxiliary equipment, not directly involved in the experiments, includes an on-line typewriter, seen in the background center of Fig. B-1, and a magnetic tape transport, seen in the right background of Fig. B-1.

The display, shown in Figs. B-1, B-2, and B-3 is a 16-inch electrostatic CRT, which is shared by two Ss. As shown in Fig. B-1, a separator is placed before the CRT to isolate the character and prompting-light displays of one S from the other S.

The character generator is the large cabinet to the left of the display in Fig. B-3. It accepts coded instructions from the computer, and generates any of a 43-character repertoire in about 6 microseconds. Coded instructions from the computer explicitly specify the position and selection of each character each time it is to be written on the display. The character generator generates the deflection and brightening signals needed by the display and, for flicker-free characters, must repeat these instructions 40 to 50 times a second. The size and brightness of characters may be specified by the computer instructions (several levels of both are available), or size and brightness may be adjusted by the operator, using control knobs, independent of the computer instructions.

The special equipment used for this experimental setup is shown in the schematic diagrams of Figs. B-4 and B-5, and in the photograph of Fig. B-6. This special equipment includes the following:

Keyset input--Response keys for subjects to strike during experiments (as shown in closeup in Fig. B-7(a) and (b), and connected in place in Fig. B-6. The contacts are coupled directly to the buffer input.

Prompting stimulus output--Either lights or air jets may be used; they plug into the same sockets. The prompting lights are shown taped on the display screen in Fig. B-6, illuminated to prompt the pattern 01010 (for character J) on the left station, and pattern 11010 (for character K) on the right station. If air jets are used, they are controlled by solenoid valves especially designed at SRI for controlling tactile-stimulus air jets (for the projects on tactile-stimulus research under Dr. James Bliss). They are worked from a line pressure of 20 psi, and can operate fast enough to give pulses up to 120 pps, which appears to be the frequency to which human touch is most sensitive, according

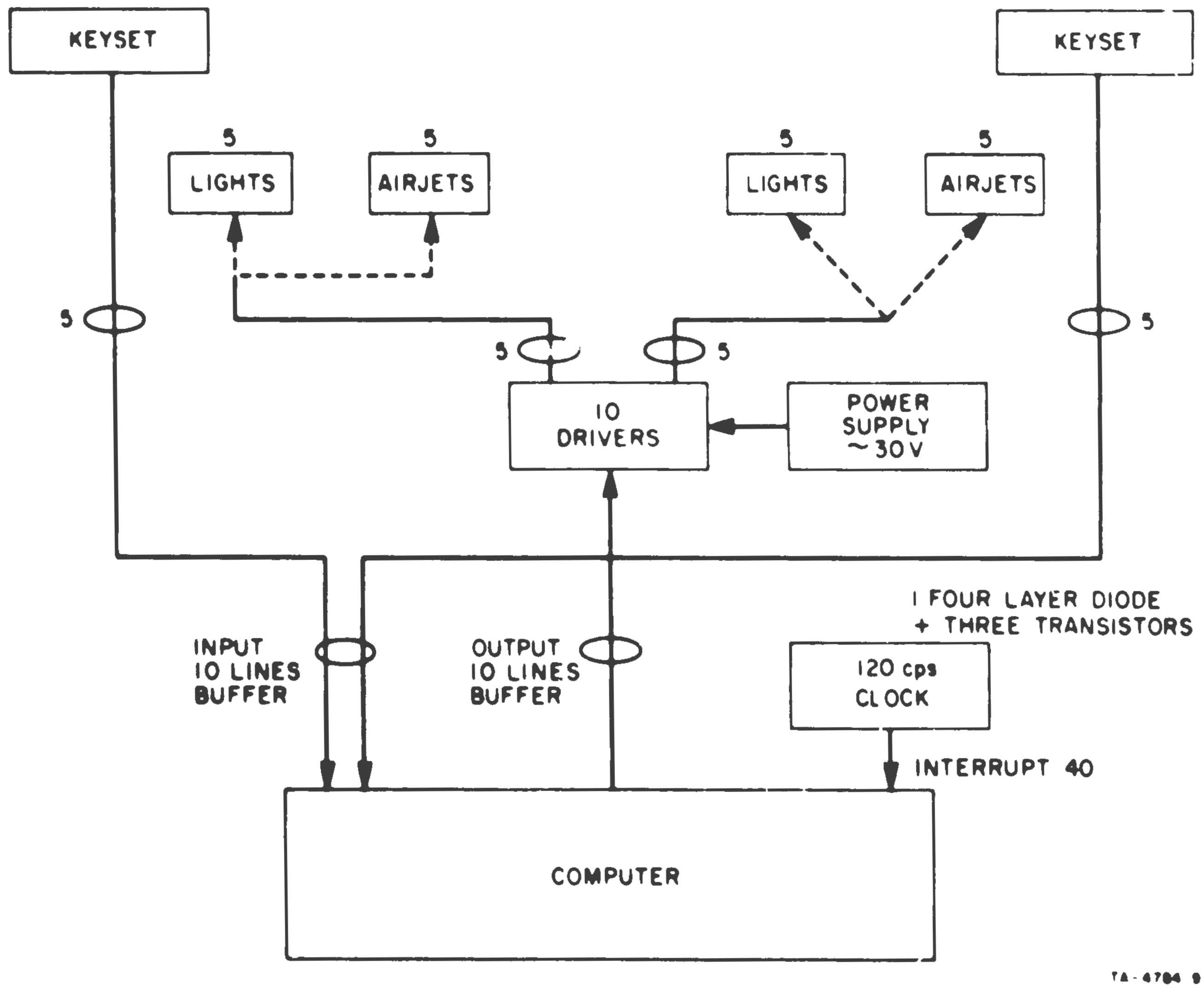
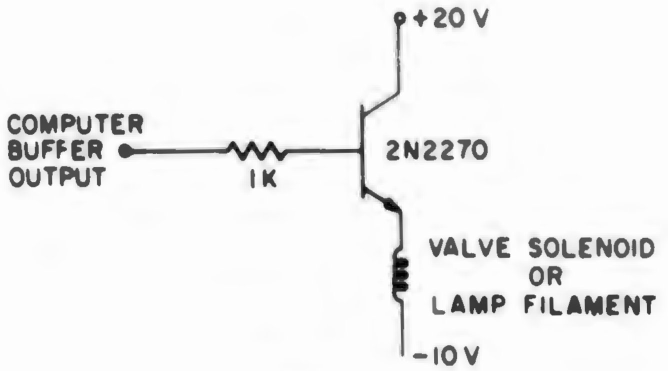
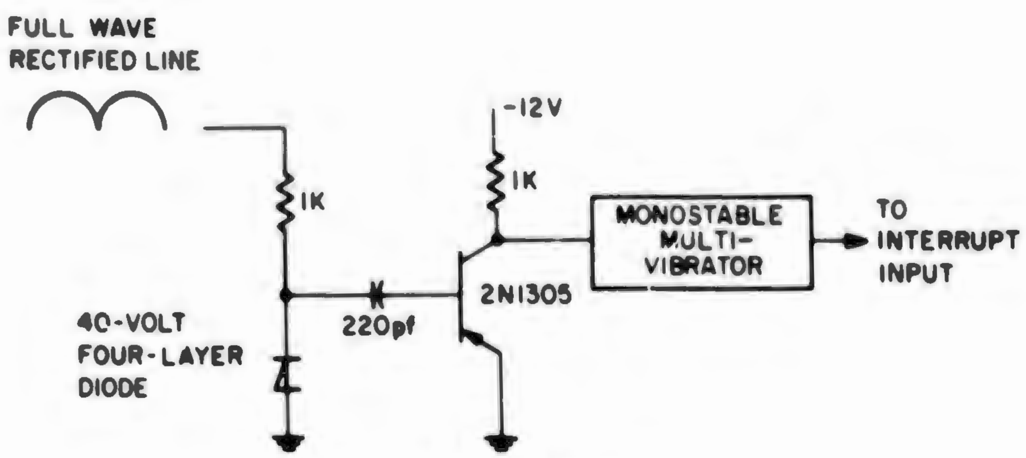


FIG. B-4 BLOCK DIAGRAM OF EQUIPMENT INTERCONNECTION



DRIVER CIRCUIT



120 cps CLOCK

TA-4784-10

FIG. B-5 COUPLING CIRCUITRY

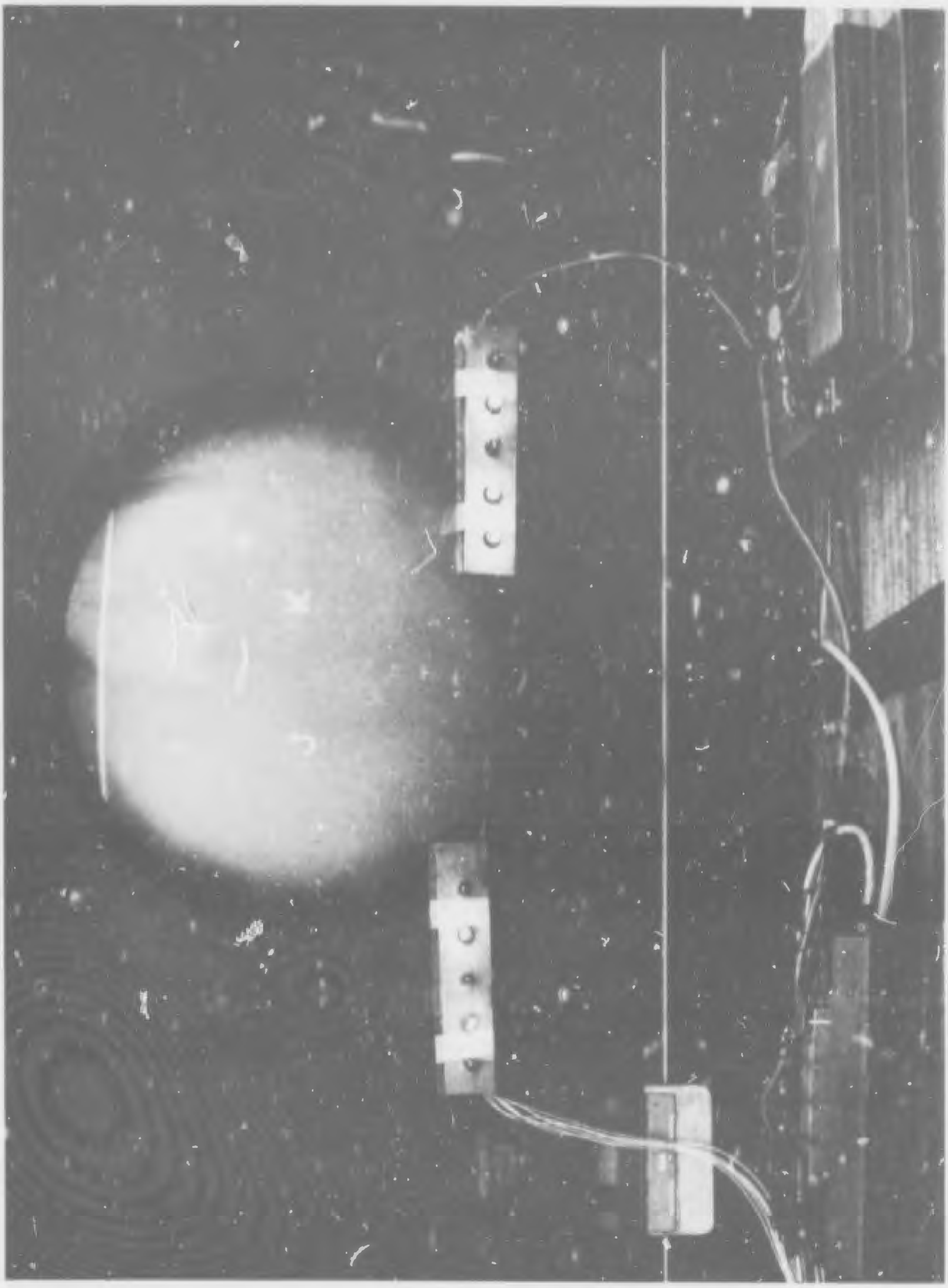


FIG. B-6 CLOSE-UP OF KEYBOARDS, VISUAL PROMPT SIGNALS, AND CRT DISPLAY

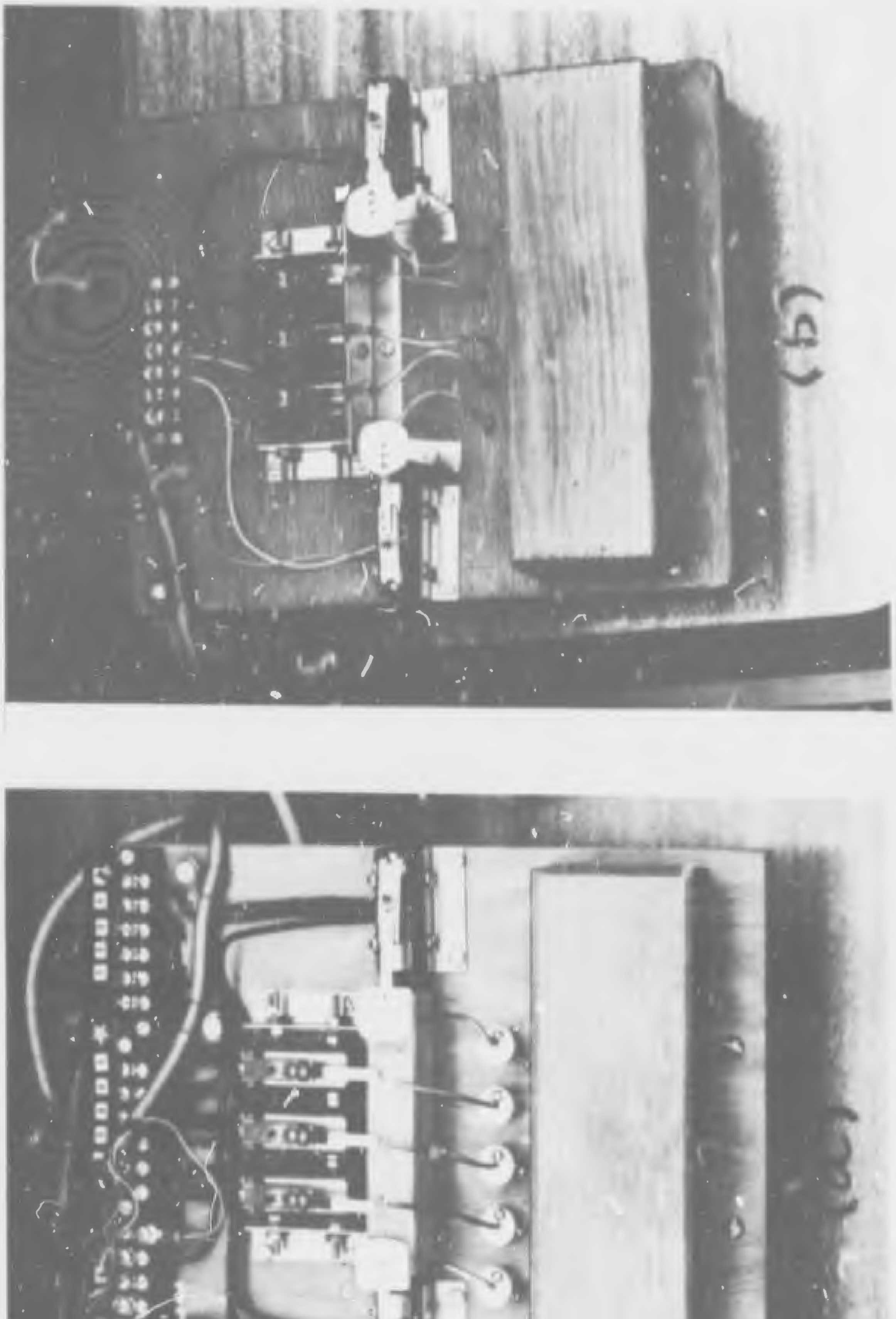


FIG. B-7 TACTILE PROMPT KEYSETS
(a) Original Keyset (Keyset A)
(b) Modified Keyset (Keyset B)

to Dr. Bliss. The air-jet solenoid valves are shown on the bottom of the keyset boards in Fig. B-7. A large plastic air-supply tube comes into the end of the valve housing, and small plastic air tubes convey the valved output air from each jet. The air will be on for TPU periods of 1/120th second, off for TPD periods of 1/120 second, then back to on. TPU (Time Pulse is Up) and TPD (Time Pulse is Down) are two integer parameters changeable by the operator. (See Sec. 4, Operating Procedures.) The keyset in Fig. B-7(b) has jets located in the keys. The keyset in Fig. B-7(a) has jets that can be freely positioned (by means of flexible brass tubing) to strike the bottoms of the fingers. Transistor drivers for the prompting-stimulus devices are coupled directly to the buffer output by means of the driver electronics seen on the near end of the chassis at the left in Fig. B-6. There is one transistor for each of the ten output signals--five signals to each station--each signal controlling either a light or an air jet, depending upon which is plugged in.

Clock input--The clock input is a 120-cps source derived from the power line. The electronics for this are located on the chassis at the left in Fig. B-6, between the power transformer and the output-driver boards. The clock input drives the Interrupt 40 input (one of the two interrupt inputs on the CDC 160A).

DATA PROCESSING AND PORTRAYAL

Two different summary printouts are available: the tabular stimulus-response-time record, and the summary trial record.

For each of the 31 different stimulus characters that can be presented recurrently during the run, the tabular record lists the different responses given during the run, how many times each response was given for that stimulus, and the accumulated response time. An example of the data tape is shown in Fig. B-8, atop a sheet of teletype printout of the analysis. The summary stimulus-response record is shown at the top (for Subject 0033), and the tabular stimulus-response-time record takes up the rest of the page. The circled numbers in the second column of the tabular record represent erroneous responses to the associated stimulus. The stimulus response patterns are represented by a decimal number--31 patterns in all--as shown on the code sheet of Appendix A.

The summary trial record shows the S's ID number, the number of correct responses and the accumulated response time in tenths of a second, the number of error responses and accumulated time, and the total number of responses and corresponding accumulated time.

Data are accumulated for the two Ss, as matrices in core, during the experimental run. At any time the operator can stop the experiment and can ask for type-out or punch-out (for later typing on the Flexowriter) of the tabular stimulus-response-time record. The operator controls the period of accumulation of this record be being able to clear the matrices for either S. Accumulation is automatic during the experiment.

FIG. B-8 PRINTOUT DATA SHEET AND SEGMENT OF PUNCHED PAPER TAPE
(Circled Numbers Denote Errors)

A separate program, for use independently of the experimentation program, processes the paper-tape record made during the experiments. The operator specifies the ID of the S whose records are to be processed, and the computer scans the tapes and extracts the stimulus, response, and time data for that S for each stimulus-response trial, accumulating this in matrices in the computer memory. The operator can punch out a summary at the end of any block of data on paper tape (each block corresponds to one run during the experiment and has trial records for both Ss). The operator may also clear the accumulation matrices at the end of any block, and may designate that either or both types of summary are to be punched out for later typing (this process makes paper tape that prints on the tape-reading teletypewriter).

OPERATING PROCEDURE

To begin the experimental run, the operator follows the procedure given: He connects and turns on all equipment, and depresses the Master Clear switch on the CDC 160A computer. He then places the program tape in the reader and loads it into Bank 0, beginning at location 0000. After the program has been loaded, the operator depresses the Master Clear switch momentarily, and then raises the Run switch. The program will immediately halt with 0000 in the A-register and 0112 in the P-register. This is the initial ID specification halt for S A.

The ID number is used during the continuous punchout in order to distinguish between different Ss and experiments. To give an ID to S A, place any value in the lower six bits of the A-register, and hit Run to continue. The program will once again halt with 0000 in the A-register and 0123 in the P-register. Set the ID number for S B in the same way, and again hit Run.

The program will halt with a ONE in the A-register and 0130 in the P-register. This is the stimulus initialization for both Ss. This may be changed to any nonzero 10-bit pattern to start the cycle at some point in the 992-character cycle length.

Once the Run switch is again hit, the program should be running in the normal experimental mode. To change any specifications, or to call for output or change modes, the operator uses the parameter-change procedure or the input-output specification. Unless changed by the operator, the parameters of the experiment are as given below with the parameter descriptions:

TDA The primary stimulus will automatically be started to S A 0.1 TDA (octal) seconds after the last response. The initial value of TDA is 0005.

SDA The cueing stimulus will automatically be delayed to S A 0.1 SDA (octal) seconds after the primary stimulus is given. The initial value of SDA is 0010.

TSA The cueing stimulus to S A will automatically be turned off after 0.1 TSA (octal) seconds unless TSA is zero (then it is turned off only after the keyset has been depressed and raised). The initial value of TSA is 0000.

TDB Same as for TDA, except for S B.

SDB Same as for SDA, except for S B.

TSB Same as for TSA, except for S B.

TPU The cueing stimulus will be on part of the time and off part of the time. TPU is the time (octal) that the cueing stimulus will be on in 1/120ths of a second. The initial value of TPU is 0001.

TPD TPD is the time (octal) that the cueing stimulus will be off, in 1/120ths of a second. The initial value of TPD is 0003.

ETL ETL is the experiment time limit. The initial value of ETL is 4 minutes.

At any time during the running of the experiment, the operator can examine or change certain specifications. He does this by turning on Selective Jump Switch 1 on the computer console. As soon as both Ss have completed their latest responses, the computer will execute the Specification Stop Routine. Halt P1, described in detail below, is the first of a series of halts. At any of these halts, the operator may turn off Selective Jump Switch 1, and the computer will resume operations where it left off.

The first halt will show a value in the P-register (P1) and a value in the A-register (A1). As long as the switch is on, each restarting of the computer will result in a new halt, next at P2 with A2, then at P3 with A3, and eventually back to P1 with A1 to repeat the cycle.

For each halt except the first and sixth, the present value of the specified variable can be changed by manually clearing the A-register and entering into it the desired value (or it can be left at the present value). What number is held in the A-register at the next restart establishes the values of the corresponding variable during the subsequent experimental run. If a continuous punch-out has been requested for either subject, the new set of specifications resulting from the entry of the new variable is automatically punched on paper tape when the operator initiates the experimental run after a Specification stop procedure.

The possible halts are as follows:

P-register	A-register	Meaning of the value in the A-register
P1 1563	A1	The stimulus pattern just applied for S A. Also for this halt, and until Halt P5 with A5, the BER-register contains the associated response pattern and the BXR-register contains the associated response time (octal) in 1/120ths of a second.

P-register	A-register	Meaning of the value in the A-register
P2 1572	A2	The octal value of TSA in tenths of a second.
P3 1615	A3	Distinguishes between SRP Modes 1 or 2 for S A. For SRP mode 1 (automatic stimulus), set the A-register to 0000. For SRP Mode 2 (sampling switch used to signal response) set the A-register to 0001.
P4 1634	A4	The octal value of TDA in tenths of a second.
P5 1657	A5	The octal value of SDA in tenths of a second.
P6 1712	A6	The same as for A1, except for S B. BER and BXR will continue to hold their given values until Halt P1 with A1 is again reached, or until Selective Jump Switch 1 is turned off and the Run switch hit.
P7 1721	A7	The octal value of TSB in tenths of a second.
P8 1745	A8	The same as for A3, except for S B.
P9 1765	A9	The octal value of TDB in tenths of a second.
P10 2010	A10	The octal value of SDB in tenths of a second.
P11 2032	A11	The octal value of TPU in 1/120ths of a second.
P12 2047	A12	The octal value of TPD in 1/120ths of a second.
P13 2064	A13	The octal value of ETL in minutes.

At any time during the running of the experiment, the operator can also perform certain input-output operations. He does this by turning on Selective Jump Switch 2 on the console. As soon as both Ss have completed their latest responses, the computer will start executing the I/Stop Routine. In addition, if the time limit ETL has been reached, the program will branch to the I/area. However, the program will halt at a P-register value of 2174 in order for the operator to turn on Selective Jump Switch 2. The program will not continue until this action is performed.

The I/Stop Routine is described as follows:

P-register	A-register	Meaning of the value in the A-register
P1 2201	A1	Indicates whether a continuously punched record should be maintained for S A. For continuous punch, set the A-register to 0001. To bypass the continuous punch, set the A-register to 0000.

P-register	A-register	Meaning of the value in the A-register
P2 2220	A2	Designates output of currently accumulated matrices for S A. For no punch or printout, set the A-register to 0000. For on-line typewriter tabulated output, set the A-register to 0001. For immediate punch for Flexowriter tabulated listing, set the A-register to 0002. When A2 is either 0001 or 0002, the specified operation will be performed immediately, and then control will continue in sequence.
P3 2241	A3	Designates whether S A should be restarted or resumed. If S A should be restarted, set the A-register to 0001; otherwise, set it to 0000 to resume A. If S A is to start over, the program will halt at P4 with A4 and at P5 with A5; otherwise, those halts will be bypassed.
P4 2243	A4	Stimulus restart value for S A. This may be changed to any nonzero 10-bit pattern.
P5 2257	A5	Designates the present ID number for S A.
P6 2273	A6	Same output information as for A1, .except for S B.
P7 2213	A7	Same output information as for A2, except for S B.
P8 2235	A8	Same restart/resume as for A3, except for S B. Halts at P9 and at P10 with A10 will be bypassed if the A-register setting is 0000.
P9 2337	A9	Same stimulus restart information as for A4, except S B.
P10 2352	A10	Same ID number information as for A5, except S B.

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Appendix C

TABLES OF EXPERIMENTAL RESULTS AND CORRELATIONS

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Table C-16	Speed and Accuracy Scores of Six Subjects on Two Different Tactile Stimulus Keysets During Practice Sessions

Table C-1

COMBINED PERFORMANCE OF NINE SUBJECTS
ON TACTILE STIMULUS DISCRIMINATION TEST

Chord Pattern	Number of Responses	Percent Correct Responses	Accuracy Ranking	Mean Response Time (sec)	Speed Ranking
1	22	100.0	1	0.80	1
2	21	95.2	2	1.02	3
3	30	86.7	4	1.40	10
4	29	86.2	5	1.04	4
5	30	93.3	3	0.85	2
1-Finger Chords	132	91.7	--	1.03	--
1 2	40	70.0	8	1.12	5
2 3	29	69.0	10	1.32	8
3 4	17	58.8	14	1.20	6
4 5	30	70.0	8	1.25	7
1 3	21	66.7	11	1.61	11
2 4	26	53.8	16.5	1.72	13
3 5	31	41.9	22	2.16	21
1 4	25	80.0	6	1.65	12
2 5	28	60.7	13	1.78	15
1 5	30	70.0	8	1.35	9
2-Finger Chords	178	64.3	--	1.51	--
1 2 3	32	53.1	18	1.76	14
2 3 4	35	57.1	15	1.89	17
3 4 5	22	45.5	20	2.29	27
1 3 4	22	27.3	29	2.09	19
2 4 5	34	41.2	23	2.21	24
1 2 4	33	42.4	21	2.17	22
2 3 5	24	37.5	26	2.16	20
1 4 5	31	48.4	19	2.51	29
1 2 5	24	33.3	28	2.04	18
1 3 5	26	23.1	31	2.23	25
3-Finger Chords	283	42.0	--	2.13	--
1 2 3 4	27	63.0	12	1.81	16
2 3 4 5	26	53.8	16.5	2.25	26
1 3 4 5	26	26.9	30	2.55	30
1 2 4 5	29	34.5	27	2.32	28
1 2 3 5	28	39.3	25	2.20	23
4-Finger Chords	136	43.4	--	2.22	--
1 2 3 4 5	15[a]	40.0	24	2.62	31
5-Finger Chord	15	40.0	--	2.62	--
All Chords	843	57.3	--	1.78	--

[a] Only 3 of the 9 subjects received the 5-finger pattern in the stimulus discrimination test.

Table C-2

COMBINED PERFORMANCE OF NINE SUBJECTS
ON VISUAL STIMULUS DISCRIMINATION TEST

Chord Pattern	Number of Responses	Percent Correct Responses	Accuracy Ranking	Mean Response Time (sec)	Speed Ranking
1	37	94.6	23	0.603	4
2	53	98.1	7	0.598	2
3	44	97.7	10	0.591	1
4	33	100.0	3.5	0.612	5
5	47	95.7	20	0.600	3
1-Finger Chords	215	97.2	--	0.600	--
1 2	41	97.6	11.5	0.680	7
2 3	39	97.4	15.5	0.687	8
3 4	38	100.0	3.5	0.703	9
4 5	39	97.4	15.5	0.679	6
1 3	39	97.4	15.5	0.777	16
2 4	32	93.8	24.5	0.747	13
3 5	46	93.5	26	0.839	20
1 4	31	96.8	19	0.768	15
2 5	34	97.1	18	0.785	17
1 5	33	100.0	3.5	0.703	10
2-Finger Chords	372	97.0	--	0.738	--
1 2 3	41	92.7	27	0.759	14
2 3 4	50	98.0	8	0.738	12
3 4 5	32	93.8	24.5	0.794	18
1 3 4	41	97.6	11.5	0.883	23
2 4 5	49	98.0	9	1.133	30
1 2 4	40	97.5	13	0.970	25
2 3 5	47	91.5	28	0.994	27
1 4 5	44	95.5	21.5	0.895	24
1 2 5	30	86.7	31	0.870	22
1 3 5	40	100.0	3.5	0.972	26
3-Finger Chords	414	95.4	--	0.906	--
1 2 3 4	43	100.0	3.5	0.828	19
2 3 4 5	44	95.5	21.5	0.861	21
1 3 4 5	39	97.4	15.5	1.151	31
1 2 4 5	39	89.7	29	1.018	28
1 2 3 5	38	89.5	30	1.058	29
4-Finger Chords	203	94.6	--	0.977	--
1 2 3 4 5	19[a]	100.0	3.5	0.732	11
5-Finger Chord	19	100.0	--	0.732	--
All Chords	1223	96.2	--	0.810	--

[a] Only 3 of the 9 subjects received the 5-finger pattern in the stimulus discrimination test.

Table C-3

CORRELATIONS AMONG SUBJECTS
ON VARIOUS STIMULUS DISCRIMINATION TEST SCORES[a]

	Total Number Responses	Mean Response Time: Total Responses	Mean Response Time: Correct Responses	Mean Response Time: Error Responses	Percent Correct Responses
Total Number Responses	.625[c]	--	--	--	--
Mean Response Time: Total Responses	--	.480[b]	.950[f]	.333	-.200
Mean Response Time: Correct Responses	--	.962[f]	.4[illegible]6[b]	.233	-.267
Mean Response Time: Error Responses	---	.783[e]	.646[d]	-.400	.483
Percent Correct Responses	--	.217	.288	.200	-.417

[a] Rank correlations (rho); N = 9. (1) Correlations between visual discrimination and tactile discrimination score ranks shown on the diagonal. (2) Correlations between score ranks in the tactile discrimination test shown above the diagonal. (3) Correlations between score ranks in the visual discrimination test shown below the diagonal.

[b] $.25 > P > .178$

[c] $.12 > P > .076$

[d] $.076 > P > .044$

[e] $.022 > P > .0082$

[f] $P < .002$

Note on probabilities: All probabilities are for two-tailed test of significance. $P > .25$ for all correlations not footnoted.

Table C-4

CUMULATIVE RECORD FOR SUBJECT TRAINED WITH AUTOMATED TACTILE PROMPTING BUT WITHOUT FEEDBACK SIGNAL

Date of Training	Time at Key-board for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Cum. Number Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
7-30-64	24	24	377	377	84.6	2.87	--	--
7-31-64	32	56	586	963	88.4	1.80	--	--
8-3-64	24	80	742	1705	91.2	1.09	--	--
8-4-64	24	104	876	2581	92.4	0.89	--	--
	6	110	235	2816	--	--	91.5	0.79
8-5-64	24	134	1018	3834	95.9	0.70	--	--
	4	138	176	4010	--	--	94.9	0.66
8-6-64	24	162	1000±	5010±	[a]	[a]	--	--
	4	166	180±	5190±			[a]	[a]
8-7-64	4	170	180±	5370±	[a]	[a]		
	6	176	283	5650±	--	--	97.2	0.56

[a] Records of numbers of trials, response times, and response accuracy not available for all trials on 8-6-64 and for practice trials on 8-7-64; cumulative number of trials estimated from 8-5-64 through 8-7-64.

Table C-5

CUMULATIVE RECORD FOR SUBJECT TRAINED WITH AUTOMATED VISUAL PROMPTING BUT WITHOUT FEEDBACK SIGNAL

Date of Training	Time at Key-board for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Cum. Number Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
7-30-64	24	24	732	732	98.4	1.05	--	--
7-31-64	32	56	864	1596	94.3	0.98	--	--
8-3-64	24	80	870	2466	98.0	0.84	--	--
8-4-64	24	104	955	3421	98.8	0.72	--	--
	6	110	248	3669	--	--	99.6	0.68
8-5-64	24	134	1035	4704	97.4	0.64	--	--
	4	138	181	4885	--	--	96.7	0.59
8-6-64	24	162	1000±	5885±	a	a	--	--
	4	166	180±	6065±	--	--	a	a
8-7-64	4	170	180±	6245±	a	a	--	--
	6	176	274	6520±	--	--	98.5	0.60

[a] Records of numbers of trials, response times, and response accuracy not available for all trials on 8-6-64 and for practice trials on 8-7-64; cumulative number of trials estimated from 8-5-64 through 8-7-64.

Table C-6

CUMULATIVE RECORD FOR SUBJECT TRAINED WITHOUT AUTOMATED PROMPTING AND WITHOUT FEEDBACK SIGNAL

Date of Training	Time at Key-board for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Practice Conditions: Cum. Number Trials thru Period	Practice Conditions: Percent Correct Responses	Practice Conditions: Mean Response Time (sec)	Test Conditions: Percent Correct Responses	Test Conditions: Mean Response Time (sec)
7-30-64	24	24	422	422	81.0	2.46	--	--
7-31-64	32	56	631	1053	94.1	1.65	--	--
8-3-64	24	80	648	1701	94.0	1.36	--	--
8-4-64	24	104	727	2428	96.1	1.10	--	--
	6	110	189	2617	--	--	95.2	1.03
8-5-64	24	134	777	3394	92.4	1.01	--	--
	4	138	129	3523	--	--	95.3	0.97
8-6-64	24	162	800±	4323±	a	a	--	--
	4	166	130±	4450±	--	--	a	a
8-7-64	4	170	140±	4595±	a	a	--	--
	6	176	220	4815±	--	--	96.4	0.77

[a] Records of numbers of trials, response times, and response accuracy not available for all trials on 8-6-64 and for practice trials on 8-7-64; cumulative number of trials estimated from 8-5-64 through 8-7-64.

Table C-7

PERFORMANCE IN 8-MINUTE TEST AT END OF TRAINING FOR SUBJECTS TRAINED DURING MAIN SERIES

Training Condition	Minutes Practice Prior to Test	Subject	No. Responses Prior to Test	Mean Response Time (seconds) Error	Correct	Total	Percent Correct Responses
No Automated Prompts	136	A	3374	1.19	1.08	1.09	93.7
		B	3118	1.44	1.25	1.28	82.9
		C	3632	0.81	0.78	0.78	96.5
		D	2959	1.35	0.88	0.93	90.0
		E	2288	2.61	1.13	1.39	82.4
		F	3564[a]	0.68	0.69	0.69	88.0
	Average of Means		--	1.35	0.97	1.03	88.9
	Std. Deviation		453.55	0.627	0.201	0.253	5.18
	Group Mean		3155.8	1.45	0.95	1.00	89.3
Visual Prompts	136	G	3503	4.41	1.90	2.30	84.2
		H	2855	2.54	1.31	1.70	68.1
		I	4073	0.99	0.80	0.83	82.3
		J	3345	0.00	1.13	1.13	100.0
		K	3326	1.13	0.93	0.93	98.9
		L	4186	0.73	0.68	0.68	96.6
	Average of Means		--	1.63	1.12	1.26	88.4
	Std. Deviation		454.02	1.454	0.403	0.566	11.39
	Group Mean		3548.0	2.11	1.01	1.12	90.1
Tactile Prompts	144	M	2758	1.20	1.02	1.02	99.2
		N	3199	1.36	0.98	1.14	57.0
		O	3837	0.96	0.84	0.85	95.3
		P	3539	0.99	1.02	1.02	94.2
		Q	3721[b]	1.23	0.88	0.91	92.3
		R	4197[b]	0.97	0.79	0.80	94.1
	Average of Means		--	1.12	0.92	0.96	88.7
	Std. Deviation		460.36	0.151	0.085	0.115	14.32
	Group Mean		3541.8	1.24	0.91	0.95	89.4
Overall Average of Means			3415.2	1.37	1.00	1.08	88.7
Overall Standard Deviation			493.44	0.910	0.299	0.387	10.98

[a] Number responses in first 8-minute practice period estimated due to error in recording.

[b] Number responses in final 12 of 32 minutes practice during the second of five practice days estimated due to damaged record tape.

Table C-8

CUMULATIVE COMBINED RECORD
FOR SUBJECTS TRAINED WITH FEEDBACK SIGNAL[a]

Date of Training	Time at Key-board for Period (min)	Time thru Period (min)	Ave. Number Trials for Period[b]	Cum. Ave. Number Trials thru Period[b]	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
12-7-64	24	24	443	443	79.9	1.83	--	--
12-8-64	28	52	559	1002	89.1	1.71	--	--
	4	56	106	1108	--	--	51.7	1.49
12-9-64	28	84	636	1744	94.3	1.29	--	--
	4	88	126	1870	--	--	82.8	1.07
12-10-64	28	116	722	2592	97.0	1.03	--	--
	4	120	141	2733	--	--	91.3	0.91
12-11-64	8	128	222	2955	97.6	0.88	--	--
	4	132	110	3065	--	--	99.1	0.91
	8	140	230	3295	97.0	0.82	--	--
	4	144	119	3414	--	--	98.0	0.77

[a] N = 3; see Appendix C for cumulative record of each of these Subjects individually.

[b] Mean values for number of trials rounded to the nearest whole number.

Table C-9

CUMULATIVE RECORD FOR SUBJECT TRAINED WITH AUTOMATED TACTILE PROMPTING AND WITH FEEDBACK SIGNAL

Date of Training	Time at Keyboard for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Cum. Number Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
12-7-64	24	24	384	384	65.1	2.37	--	--
12-8-64	28	52	496	880	77.0	2.05	--	--
	4	56	105	985	--	--	67.6	1.50
12-9-64	28	84	612	1597	94.3	1.30	--	--
	4	88	133	1730	--	--	92.5	0.97
12-10-64	28	116	723	2453	97.6	0.99	--	--
	4	120	145	2598	--	--	97.9	0.83
12-11-64	8	128	232	2830	99.1	0.75	--	--
	4	132	118	2948	--	--	97.4	0.79
	8	140	224	3172	98.7	0.88	--	--
	4	144	122	3294	--	--	98.4	0.75

Table C-10

CUMULATIVE RECORD FOR SUBJECT
TRAINED WITH AUTOMATED VISUAL PROMPTING
AND WITH FEEDBACK SIGNAL

Date of Training	Time at Key-board for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Cum. Number Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
12-7-64	24	24	530	530	82.6	1.13	--	--
12-8-64	28	52	621	1151	95.5	1.35	--	--
	4	56	108	1259	--	--	56.5	1.37
12-9-64	28	84	663	1922	93.5	1.13	--	--
	4	88	130	2052	--	--	81.5	0.95
12-10-64	28	116	723	2775	95.9	0.98	--	--
	4	120	140	2915	--	--	78.6	0.91
12-11-64	8	128	213	3128	98.1	0.93	--	--
	4	132	104	3232	--	--	100.0	0.98
	8	140	227	3459	96.9	0.80	--	--
	4	144	115	3574	--	--	99.1	0.78

Table C-11

CUMULATIVE RECORD FOR SUBJECT
TRAINED WITHOUT AUTOMATED PROMPTING BUT WITH FEEDBACK SIGNAL

Date of Training	Time at Key-board for Period (min)	Cum. Time thru Period (min)	Number Trials for Period	Cum. Number Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
12-7-64	24	24	414	414	90.1	2.23	--	--
12-8-64	28	52	560	974	92.7	1.81	--	--
	4	56	104	1078	--	--	30.8	1.60
12-9-64	28	84	632	1710	95.1	1.46	--	--
	4	88	116	1826	--	--	73.3	1.33
12-10-64	28	116	720	2546	97.4	1.12	--	--
	4	120	138	2684	--	--	97.1	1.00
12-11-64	8	128	220	2904	95.5	0.96	--	--
	4	132	107	3011	--	--	100.0	0.99
	8	140	238	3249	95.4	0.77	--	--
	4	144	121	3370	--	--	96.7	0.78

Table C-12

CUMULATIVE COMBINED RECORD FOR SUBJECTS TRAINED WITHOUT FEEDBACK SIGNAL[a]

Day	Ave. Time at Key-board for Period (min)	Cum. Ave. Time thru Period (min)	Ave. Number Trials for Period	Cum. Ave. Number Trials thru Period	Practice Conditions: Percent Correct Responses	Practice Conditions: Mean Response Time (sec)	Test Conditions: Percent Correct Responses	Test Conditions: Mean Response Time (sec)
1	24[b] 24 24	24 24.0 24	215 446.3 636	215 446.3 636	35.0 83.4 98.8	1.09 2.37 5.86	--	--
2	28 30.7 32	52 54.7 56	425 677.1 856	640 1123.4 1439	62.6 90.4 99.7	0.84 1.76 3.68	--	--
2	0 1.3 4	56 56.0 56	0 26.9 105	640 1150.3 1502	--	--	28.8 61.2[c] 100.0	1.16 1.88[c] 2.72
3	24 26.7 28	80 82.7 84	396 656.7 822	1036 1807.0 2324	69.5 91.4 100.0	0.86 1.50 2.80	--	--
3	4 5.3 8	88 88.0 88	71 141.6 273	1154 1948.6 2426	--	--	43.2 79.5 100.0	0.79 1.47 3.31
4	16 18.7 24	104 106.7 112	317 513.4 863	1569 2462.0 2935	79.1 92.3 100.0	0.77 1.27 2.13	--	--
4	8 8 8	112 114.7 120	137 226.4 305	1752 2688.4 3240	--	--	50.5 84.0 99.5	0.76 1.25 2.22
5	24 24 24	136 138.7 144	536 749.8 996	2288 3438.2 4197	79.3 92.4 99.3	0.72 1.12 1.81	--	--
5	8 8 8	144 146.7 152	158 263.2 358	2481 3701.4 4544	--	--	57.0 88.6 100.0	0.68 1.08 2.30

[a] Includes all Ss from 3 groups trained between 9-14-64 and 10-2-64 (N = 18).

[b] Top and bottom figures in each triad denote minimum and maximum values for all Ss; underscored middle figure is the weighted mean for all Ss combined.

[c] Only "visual prompt" group (N = 6) tested on Day 2.

Table C-13
CUMULATIVE RECORD FOR SUBJECT
TRAINED AND RETRAINED WITHOUT AUTOMATED PROMPTING[a]

Date of Training	Time at Key-board for Period (min)	Cum. Time at Key-board thru Period (min)	Number Trials for Period	Cum. Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
9-14-64	24	24	473	473	93.0	1.95	--	--
9-15-64	32	56	743	1216	96.6	1.50	--	--
9-16-64	28	84	768	1984	96.5	1.17	--	--
	4	88	124	2108	--	--	95.2	0.95
9-17-64	16	104	493	2601	92.7	0.92	--	--
	8	112	269	2870	--	--	84.4	0.82
9-18-64	24	136	762	3632	92.3	0.86	--	--
	8	144	257	3889	--	--	96.5	0.78
12-7-64	8	152	172	4061	94.2	1.60	--	--
	4	156	98	4159	--	--	89.8	1.27
	8	164	217	4376	91.7	1.03	--	--
	4	168	115	4491	--	--	96.5	0.90
12-8-64	12	180	355	4846	94.4	0.84	--	--
	4	184	126	4972	--	--	86.5	0.73
	12	196	372	5344	93.3	0.76	--	--
	4	200	123	5467	--	--	91.1	0.80
12-9-64	12	212	376	5843	91.2	0.74	--	--
	4	216	129	5972	--	--	96.9	0.68
	12	228	396	6368	91.7	0.66	--	--
	4	232	173	6541	--	--	98.8	0.68
12-10-64	12	244	400	6941	87.8	0.65	--	--
	4	248	137	7078	--	--	87.6	0.62
	12	260	404	7482	88.4	0.64	--	--
	4	264	190	7672	--	--	92.1	0.63
12-11-64	8	272	265	7937	89.1	0.66	--	--
	4	276	138	8075	--	--	88.4	0.60
	8	284	272	8347	88.6	0.62	--	--
	4	288	187	8534	--	--	92.0	0.63

[a] No response feedback signal during period 9-14 through 9-18-64. Response feedback signal introduced 12-7-64 and available throughout the balance of training.

Table C-14

CUMULATIVE RECORD FOR SUBJECT TRAINED AND RETRAINED WITH AUTOMATED VISUAL PROMPTING[a]

Date of Training	Time at Key-board for Period (min)	Cum. Time at Key-board thru Period (min)	Number Trials for Period	Cum. Trials thru Period	Practice Conditions: Percent Correct Responses	Practice Conditions: Mean Response Time (sec)	Test Conditions: Percent Correct Responses	Test Conditions: Mean Response Time (sec)
9-21-64	24	24	528	528	83.5	1.37	--	--
9-22-64	28	52	658	1186	93.6	1.14	--	--
	4	56	83	1269	--	--	53.0	1.64
9-23-64	28	84	676	1945	93.8	1.21	--	--
	4	88	93	2038	--	--	87.1	1.35
9-24-64	16	104	372	2410	96.0	1.23	--	--
	8	112	186	2596	--	--	93.0	1.33
9-25-64	24	136	730	3326	94.7	1.01	--	--
	8	144	280	3606	--	--	98.9	0.93
12-7-64	8	152	178	3784	94.9	1.27	--	--
	4	156	78	3862	--	--	80.8	1.68
	8	164	182	4044	93.4	1.21	--	--
	4	168	97	4141	--	--	99.0	1.09
12-8-64	12	180	315	4456	95.9	0.95	--	--
	4	184	114	4570	--	--	97.4	0.82
	12	196	327	4897	96.9	0.91	--	--
	4	200	113	5010	--	--	97.3	0.86
12-9-64	12	212	329	5339	96.7	0.90	--	--
	4	216	114	5453	--	--	99.1	0.83
	12	228	371	5824	96.8	0.83	--	--
	4	232	151	5975	--	--	94.7	0.75
12-10-64	12	244	348	6323	98.6	0.81	--	--
	4	248	123	6446	--	--	100.0	0.74
	12	260	369	6815	98.1	0.73	--	--
	4	264	161	6976	--	--	96.3	0.73
12-11-64	8	272	239	7215	93.7	0.78	--	--
	4	276	121	7336	--	--	93.4	0.78
	8	284	283	7619	96.8	0.73	--	--
	4	288	161	7780	--	--	91.3	0.71

[a] No response feedback signal during period 9-21 through 9-25-64. Response feedback signal introduced 12-7-64 and available throughout the balance of training.

Table C-15

CUMULATIVE RECORD FOR SUBJECT
TRAINED AND RETRAINED WITH AUTOMATED TACTILE PROMPTING[a]

Date of Training	Time at Key-board for Period (min)	Cum. Time at Key-board thru Period (min)	Number Trials for Period	Cum. Trials thru Period	Practice Conditions		Test Conditions	
					Percent Correct Responses	Mean Response Time (sec)	Percent Correct Responses	Mean Response Time (sec)
9-28-64	24	24	560	560	35.0	1.74	--	--
9-29-64	32	56	728	1288	62.6	1.86	--	--
9-30-64	24	80	530	1818	79.1	1.96	--	--
	8	88	249	2067	--	--	67.5	1.19
10-1-64	24	112	667	2734	90.7	1.42	--	--
	8	120	255	2989	--	--	92.2	1.20
10-2-64	24	144	848	3837	93.5	0.97	--	--
	8	152	301	4138	--	--	95.3	0.85
12-7-64	8	160	154	4292	93.5	1.83	--	--
	4	164	87	4379	--	--	81.6	1.53
	8	172	176	4555	96.0	1.49	--	--
	4	176	102	4657	--	--	92.2	1.17
12-8-64	12	188	291	4948	94.2	1.22	--	--
	4	192	111	5059	--	--	94.6	0.90
	12	204	328	5387	95.4	0.96	--	--
	4	208	107	5494	--	--	99.1	1.02
12-9-64	12	220	352	5846	95.2	0.82	--	--
	4	224	118	5964	--	--	94.1	0.86
	12	236	355	6319	96.1	0.81	--	--
	4	240	159	6478	--	--	99.4	0.80
12-10-64	12	252	357	6835	97.5	0.80	--	--
	4	256	123	6958	--	--	98.4	0.78
	12	268	405	7363	96.5	0.76	--	--
	4	272	166	7529	--	--	98.2	0.76
12-11-64	8	280	240	7769	94.2	0.79	--	--
	4	284	128	7897	--	--	98.4	0.70
	8	292	251	8148	94.4	0.70	--	--
	4	296	173	8321	--	--	96.0	0.71

[a] No response feedback signal during period 9-28 through 10-2-64. Response feedback signal introduced 12-7-64 and available throughout the balance of training.

Table C-16

SPEED AND ACCURACY SCORES OF SIX SUBJECTS
ON TWO DIFFERENT TACTILE STIMULUS KEYSETS DURING PRACTICE SESSIONS

Subject	Keyset[a]	Mean Total Response Time (sec)						Percent Correct Responses					
		Day 1	Day 2	Day 3	Day 4	Day 5	All Days	Day 1	Day 2	Day 3	Day 4	Day 5	All Days
M	A	6.41	3.53	2.58	1.54	1.07	2.17	72.3	90.3	95.7	96.1	98.0	94.5
	B	5.62	3.84	3.32	1.58	1.09	2.59	92.0	89.4	98.3	97.8	96.6	95.3
N	A	1.91	2.17	2.22	1.97	1.86	2.03	45.1	67.3	76.9	79.2	85.7	69.3
	B	2.16	2.27	2.00	2.32	1.79	2.08	51.0	62.7	66.0	79.1	76.2	67.4
O	A	1.62	1.74	1.73	1.39	0.98	1.46	33.8	66.7	75.7	90.6	92.4	72.8
	B	2.03	1.98	2.23	1.48	0.98	1.65	37.6	58.3	82.9	90.9	95.0	76.2
P	A	3.14	1.88	1.41	1.11	0.95	1.43	95.0	94.1	91.4	94.1	96.6	94.3
	B	2.72	2.20	1.47	1.06	1.09	1.56	95.9	92.9	97.7	95.7	95.8	95.7
Q	A	4.04	2.43	1.36	1.14	0.87	1.63	89.3	98.6	92.4	90.3	84.5	90.1
	B	4.43	3.49	1.54	1.13	0.95	1.64	84.1	93.1	90.2	79.7	82.4	84.7
R	A	2.90	2.12	1.09	0.89	0.81	1.28	72.7	87.1	86.9	95.4	95.2	89.9
	B	4.19	2.00	1.29	1.06	0.82	1.41	81.1	98.8	95.5	96.7	95.6	95.4
Averages[b]	A	3.37	2.31	1.73	1.34	1.09	1.67	68.0	84.0	86.5	91.0	92.1	85.2
	B	3.52	2.63	1.98	1.44	1.12	1.82	73.6	82.5	88.4	90.0	90.3	85.8

[a] Keyset A: Air jets mounted externally to the keys.
Keyset B: Air jets installed in the keys.

[b] Average of means; not weighted according to number of responses per subject per day. Means for "all days" considers the cumulative number of responses and aggregate times for subjects over all days.