NASA CONTRACTOR REPORT

NASA CR-1251

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SKILL TRAINING FOR THE PRODUCTION OF A MEMORIZED MOVEMENT PATTERN

by Margaret Robb and Richard W. Pew

Prepared by
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Mich.
for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1968

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PREFACE

The report that follows is based on a dissertation of Miss Margaret Robb that was submitted in partial fulfillment of the requirements for a Ph.D. degree in Physical Education at the University of Michigan in 1966. The members of her doctoral committee were Professor Katherine L. Ley, Chairman, Professor Robert W. Dixon, Professor Nelson G. Lehsten, and Professor Richard W. Pew. Miss Robb's thesis was unique in that it attempted to bring features of a physical education skill into the laboratory for analytic study. It was carried out under NASA support Contract No. NASr-54(06) because it attacked a problem that is as relevant to skills required of pilots and astronauts as it is to athletic skills. The original thesis was written for an audience of physical educators. In producing this report the manuscript has been revised in order to emphasize its relevance to skill training of a type frequently required for operation of man-machine systems.

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CHAPTER I

INTRODUCTION

Many skilled tasks require execution of a movement pattern directed toward a specific goal. However the individual performing the movement lacks information about how well he is doing until the movement pattern is completed; instantaneous error information is not available along the way. Although this kind of task has not frequently been studied in the laboratory, it is very common in practical situations. A golfer perfecting his swing, a pilot executing a procedural turn under VFR conditions, and an astronaut performing extra-vehicular maneuvers are typical examples. The question to be attacked in this report concerns the evaluation of several possible procedures for training human operators in the execution of this class of movement.

Although some tasks of this sort are terminal control problems that are effectively path independent, in the examples cited there is a desirable temporal pattern for the entire movement that will converge on the terminal state relatively optimally. In the case of the movement to be studied here, it was assumed that such a desired temporal pattern did indeed exist and that the quality of performance could be measured by noting deviations from that desired pattern.

The perspective of this research assumes that man may be regarded as an information processing system. He accepts information via his sensory organs; it is then suitably transformed by a central decision-making system to be translated into overt motor performance by a response or output system. Sensory input information may arrive from two sources. The environment can provide both command information; that is, information about the desired course of action; and feedback, information about the state of the system output at any point in time. This output information may be fed back via vision, audition, touch, proprioception, etc. If an operator is to learn, that is, to modify his behavior on the basis of previous stimulation, feedback about the state of the system output with respect to some desired goal is virtually essential. Although many other variables may contribute to the efficiency of training, without feedback, or knowledge of results, there can be no learning.

This study examines the efficacy of several kinds of feedback information administered during a training period for improving performance at the task of generating a response pattern essentially from memory.

After a brief review of definitions and concepts concerned with the regulation of feedback in Chapter 2, the subsequent chapters present the method, the results, and the discussion of the research that was undertaken.

CHAPTER 2

THE ROLE OF FEEDBACK IN SKILLED PERFORMANCE

As Bilodeau and Bilodeau (1961) have said, "studies of feedback show it to be the strongest, most important variable controlling performance and learning" (p. 250). It is for this reason that psychologists and educators have been interested in a more careful definition of the role of feedback in changing the behavior of an individual. It is generally accepted that feedback can serve a regulating, reinforcing, and/or motivating function. It is regulating in the sense that moment-by-moment feedback provides information relevant to the organization of the next response phase. It is reinforcing in the sense that knowledge of results of good performance increases the probability of repeating a similar response pattern. It is motivating in the sense that knowledge of results stimulates the operator to try harder on the subsequent trials.

Workers concerned with the analysis of knowledge of results have provided a three-parameter classification of feedback information. One parameter reflects the time of arrival of the information about performance. If the information is ongoing or is provided for moment-to-moment regulation of behavior it is referred to as concurrent feedback. If, on the other hand, feedback takes the form of a summary score given to the operator after a particular trial has been completed, it is labeled terminal feedback. Feedback is further distinguished by the class of sensory mode from which it is received. Feedback may be external or internal. Internal feedback refers to information from receptor organs concerning action within the body itself. Proprioceptive feedback is the most important example. Vision, hearing, and touch are sensors that provide external feedback and convey knowledge of events happening outside the body. Finally one may distinguish between intrinsic and augmented feedback. Information that is inherent in the task and which may be a result of the operator's own actions is called intrinsic feedback. If, on the other hand, the information provided to the operator is supplementary to that which he can obtain for himself, it is called augmented feedback. (Annet and Kay, 1957)

In terms of this classification system the error signal provided to the operator in a compensatory tracking task is an example of concurrent, external, intrinsic feedback. The integrated-absolute-error score provided to the operator at the end of a trial is an example of terminal, external, augmented feedback.

There is very little literature concerning the central problem to be attacked here; namely, what are the appropriate modes of feedback in order to optimize training for the performance of a pattern of movement in which no concurrent feedback will be available and the task must essentially be performed open-loop from memory. Is it better simply to practice the required movement and provide terminal feedback after each trial? Or would some form of concurrent feedback be more helpful?

Although this is the type of task frequently encountered in athletic skills, little formal analysis of feedback modes during training has been performed. For example, Berlin (1959) studied the effects of different teaching methods during the early learning of motor skills. She reported nothing quantitative but found that following a general orientation to the task, the learning of a selected skill by the beginner was greatly fostered by direct, uninterrupted practice. Demonstrations by skilled performers, visual aids, and verbal instructions in combination with uninterrupted practice were also effective methods. Visual aids and verbal analysis by themselves ranked low in value as aids to learning. Demonstrations were thought to play an important role in aiding students to gain insight into the objectives of the skill and to motivate the learners.

In physical education studies where specific attempts were made to increase the information obtained through internal feedback, utilizing the kinesthetic or proprioceptive mode, conflicting results have arisen. Cox (1933) and Griffith (1931) found that emphasizing kinesthetic awareness improved learning ability in a specified task, while Coady (1950), McGrath (1947), and Roloff (1953) found that special attempts of the instructor to emphasize kinesthetic awareness did not improve the ability of students to perform the task. The work of Fleishman (See Gagne and Fleishman, 1959) indicate that the importance of proprioceptive or kinesthetic information may vary during the course of learning, and this could account for the mixed results of the studies just cited.

If kinesthetic internal feedback is important to the learning of skills, then one might expect that individuals with greater "kinesthetic sensitivity" might be more successful in athletic skills. Phillips and Summers (1954) found a positive relationship between kinesthetic ability, as measured by accuracy in the performance of blind positioning movements, and bowling ability. However, Witte (1962) found no significant relationship between ball rolling ability of elementary school children and a similar measure of kinesthetic positioning accuracy. Mumby (1953) found a significant relationship between ability to maintain a constant muscular pressure under a dynamic changing condition and wrestling ability.

Psychologists have more frequently studied training for tracking tasks than for performance of a memorized temporal pattern. However, Lincoln (1956) trained a group of operators to turn the handwheel of a machine at a constant, specified rate. Three methods were tested. One group received concurrent, verbal, augmented feedback about their rate errors while they were attempting to turn the wheel. A second group grasped the handwheel while it was turned automatically at the prescribed rate. Any feedback they received was internal and concurrent. After each practice trial the third group grasped the knob of the handwheel while it turned automatically at a rate equivalent to their average error rate on the preceeding trial, an example of terminal, internal augmented feedback. After training, the operators were tested for their ability to produce the prescribed rate without the aid of any augmenting cues. Groups 1 and 3 performed best during the testing phase, which indicated that some form of augmented feedback was preferable to reliance on intrinsic cues alone.

Gordon (1959) performed an extensive study of the transfer of training among four classes of movement tasks. The first two tasks consisted of a standard pursuit tracking task and a standard compensatory tracking task. The third task was a pursuit tracking task in which the cursor had been turned off. Gordon called this the Response Memory Condition. It required the subject to reporduce the movements of a visual target by generating a movement pattern in the absence of comparable visual information about his own output. His fourth task was a pursuit tracing task with the target turned off, which he called the Pattern Memory Condition. It corresponds closely to the memorized movement pattern condition to be studied here. After being trained in one of these four conditions, each of the groups was divided into four subgroups. One of the subgroups was tested on the task it experienced during training, while the other three each transferred to one of the other training conditions, which was for them a new test condition. Of interest for our present purposes is the relative usefulness of practice under each of the four training conditions for performance of the pattern memory task. Pattern memory training proved to be the best of the four conditions for pattern memory test performance which indicates the importance of training in the specific components of the task to be performed.

Summary. Neither the physical education literature nor the psychology literature provided any clear guidelines as to appropriate modes of feedback during training for the production of memorized movement patterns. Therefore the purpose of this study was to investigate training techniques involving different types of feedback provided with differential frequency for learning a specified arm movement pattern. It was hypothesized that provision of external or augmented feedback would lead to more efficient training and improved subsequent performance.

CHAPTER 3

METHOD

Introduction. Briefly, the study consisted of training 5 groups of subjects, each under a different feedback condition, in the execution of a distinctive movement pattern. In a subsequent test condition all groups attempted to reproduce the movement pattern without the aid of any external concurrent feedback.

The pattern. The precise movement pattern to be executed was selected relatively arbitrarily, but with the intent to be representative of a typical sport movement. The exact pattern is shown in Figure 1 as a function of time. As may be seen there, its peak to peak amplitude was 10 centimeters on the visual display and the movement was completed in 3.46 seconds.

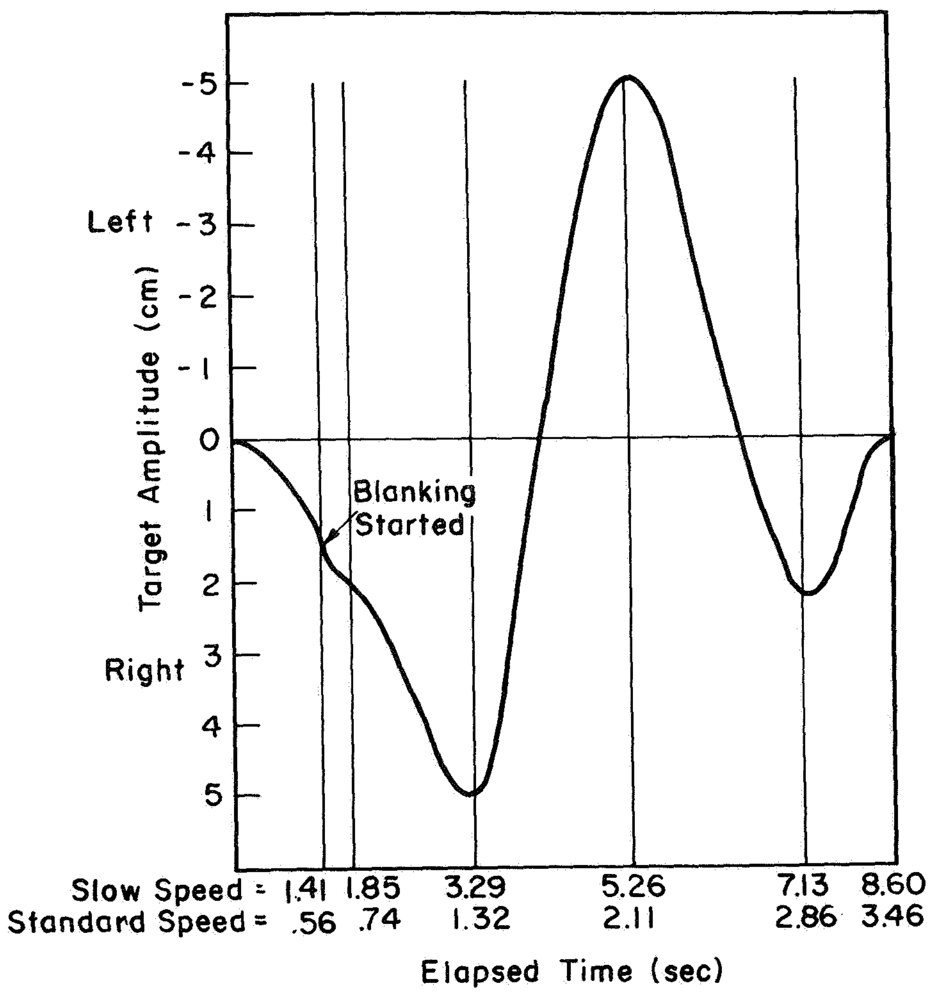

Figure 1. Amplitude-Time Pattern of the Input Signal

Also shown in Figure 1 is the time scaling for the slow-speed conditions to be described below.

Feedback conditions. Five conditions of training, reflecting different modes of feedback, were studied. They were called Blanked, Vision, Vision-Blanked, Passive-Active, and Slow-Standard. These training methods were selected because either they resembled techniques generally accepted as useful in physical education or it was hypothesized that they might be more effective than the traditional methods.

The training conditions are described in detail below.

Group 1, Vision. The Vision Group performed a standard pursuit tracking task. Concurrent feedback was obtained from viewing the position of the target and cursor on a cathode ray tube during each trial and from internal cues obtained through manipulation of the control stick. The subjects were instructed to superimpose the cursor on the target as accurately as they could.

The Vision Group subjects received two types of terminal feedback. The integrated-absolute-error score was reported to them after each trial. In addition, immediately following trials 10, 20, and 30, subjects got up from the testing booth and were shown the graphic records of their performance generated by an X-Y plotter. By comparing their output with the desired input pattern they could identify the points at which they were in error during the performance of the last previous trial. They then returned to the booth and completed the next 10 practice trials.

Group 2, Blanked. Subjects in this group performed the same pursuit tracking task, but only for the first 0.5 seconds of the trial. For the remaining 3 seconds both the target and the cursor were blanked out, and the subject was required to rely on cues provided by manipulation of the control device and his memory of the pattern in order to perform the movement.

These subjects also received the same two forms of terminal feedback as did the subjects in the vision group. Integrated-absolute-error scores were reported after each trial, and they viewed graphic records after the 10th, 20th, 30th, and 40th trials.

The blanked condition was also the condition under which all the subjects were tested subsequent to their training sessions. Thus during the testing period the subjects in this group simply continued practicing the task they had been performing during training.

Group 3, Vision-Blanked. This group was trained by alternating groups of 10 trials under the conditions specified for Group 1 and Group 2. They performed the first and third blocks of 10 trials as a pursuit tracking task, receiving concurrent visual error feedback. They also received terminal feedback after each trial in the form of integrated-absolute-error scores. During the second and fourth blocks of 10 trials the subjects performed the blanked task, i.e., the target and cursor were blanked out after 0.5 seconds of the task during each of these blocks of 10 trials. The subjects were told their integrated-absolute-error scores during these blocks and also viewed the X-Y plotter graphic records immediately following the 2nd and 6th trial of these blocks.

Group 4, Passive-Active. The subjects in Group 4 alternated blocks of trials in which they performed the pursuit tracking task or passively observed the input movement pattern without moving the control stick. The subjects were instructed to remove their hand from the control device and merely watch the target traverse the screen in the desired pattern. This passive mode was employed in the first and third blocks of 10 trials, while pursuit tracking was performed during the second and fourth blocks.

The subjects in the Passive-Active Group received terminal feedback in the form of integrated-absolute-error scores during the pursuit tracking blocks but were not provided with any graphic knowledge of results. Concurrent visual feedback was available during the active participation phase. During the passive observation trials, the subject had an opportunity to concentrate on the path of the target but did not receive any internal information from actually performing the movement or any visual error information.

Group 5, Slow-Standard. Subjects in this group practiced the movement pattern as a pursuit tracking task under two different speeds of movement. During the first and third blocks of 10 trials the speed of the target movement was scaled down so that the complete amplitude pattern required 8.6 seconds to complete. (See Figure 1) During the second and fourth blocks the standard speed, which required 3.46 seconds to complete, was utilized. Under these two types of practice the amplitude pattern remained the same, only the speed at which the target traversed the screen was modified. Therefore, during the slower speed trials, the subjects had more time to visualize the amplitude pattern of the target. However, they were reminded at the beginning of each parctice session that the criterion task to be performed after several days of practice would require execution of the movement pattern at the faster of the two speeds. At both speeds feedback information for this group consisted of terminal error scores and concurrent visual error information. They did not have an opportunity to view the graphic records on the X-Y plotter.

A summary of the feedback modes emphasized under each condition in the study and the trials on which they were administered is presented in Table 1. As can be seen from this table, the main variables under study were the types of terminal and concurrent feedback administered to the subjects through internal and external modes.

Subjects. Forty right-handed University of Michigan undergraduate students, twenty men and twenty women, served as paid subjects. Their ages ranged from 18 to 23 years. Males and females were randomly assigned to the five different groups so that each group consisted of four men and four women.

Apparatus. The arm movement pattern to be learned was displayed to the subjects as a target moving in the desired pattern on a 5-inch Fairchild Oscilloscope (See Figure 2, A).

The subject grasped the handle of the control device and moved the control (see Figure 2, C) in a horizontal plane, which in turn moved a cursor on the display. By moving the control properly the cursor could be superimposed over the target. The subject was instructed to keep the entire lower arm resting on the control device while performing the movement; however, the elbow was not constrained (the elbow rest shown in Figure 2, C was removed from the control device for this experiment.)

Table 1

SUMMARY OF FEEDBACK MODES AND TRIALS ADMINISTERED DURING TRAINING SESSIONS

Groups	BLANKED				VISION				VISION-BLANKED				PASSIVE-ACTIVE				SLOW-STANDARD			
Trials	1-10	11-20	21-30	31-40	1-10	11-20	21-30	31-40	1-10	11-20	21-30	31-40	1-10	11-20	21-30	31-40	1-10	11-20	21-30	31-40
Feedback Modes																				
1. Concurrent																				
A. Internal																				
Proprioceptive	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x
B. External																				
Visual Input					x	x	x	x	x		x		x	x	x	x	x	x	x	x
Visual Output					x	x	x	x	x		x			x		x	x	x	x	x
Error					x	x	x	x	x		x			x		x	x	x	x	x
2. Terminal																				
IAE	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x
Graphic	10	20	30	40	10	20	30	40		12, 16		32, 36								

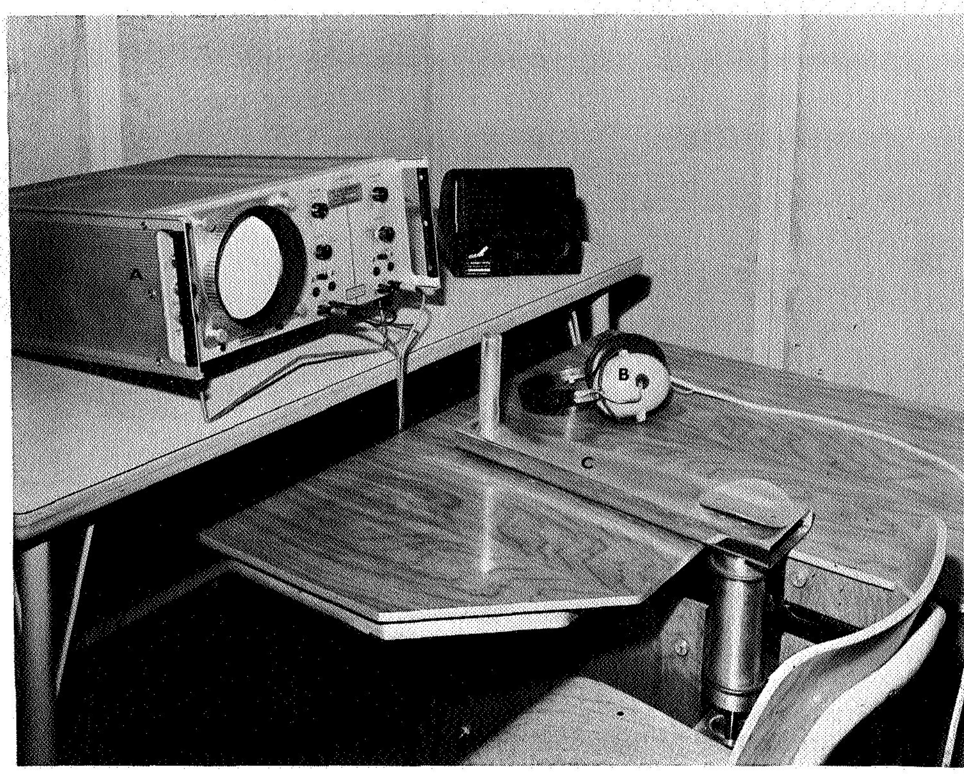

Figure 2. Illustration of Display and Control Equipment Used by the Subject

The maximum control deflection of the stick was ± 35 degrees. The specific dynamic characteristics of the stick were: (1) inertia of 0.0312 slug ft^2/radian, (2) negligible viscous damping, and (3) no external springs (the springs pictured in Figure 2 just below the control stick were removed during this experiment).

The subject wore Willson Sound Barrier earphones (see Figure 2, B) which allowed the experimenter to communicate with him. During the absence of communication a moderate intensity white noise served to mask the auditory cues generated by the apparatus.

The Experimenter's equipment consisted of an analog computer, associated electronic componenets, a Veriplotter Model 100 X-Y Plotter, and an eight-channel Brush Instrument Co. pen recorder. These devices are shown in Figure 3 and are labeled A, B, and C, respectively. The tape recorder pictured there was not used in this experiment.

<u>Performance measures</u>. Integrated-absolute-error, given by $\int_0^T |e|dt$ was recorded for each trial. In addition continuous records of the subject's performance were obtained on the 8-channel pen recorder. The input signal, the subject's output signal, and the difference between the two (error) were recorded as the subject performed the movement pattern. Selected trials were also recorded on the X-Y plotter. A graph of the input pattern was superimposed over the subject's output pattern, and this combined graph provided an additional form of feedback for some of the groups, as described heretofore.

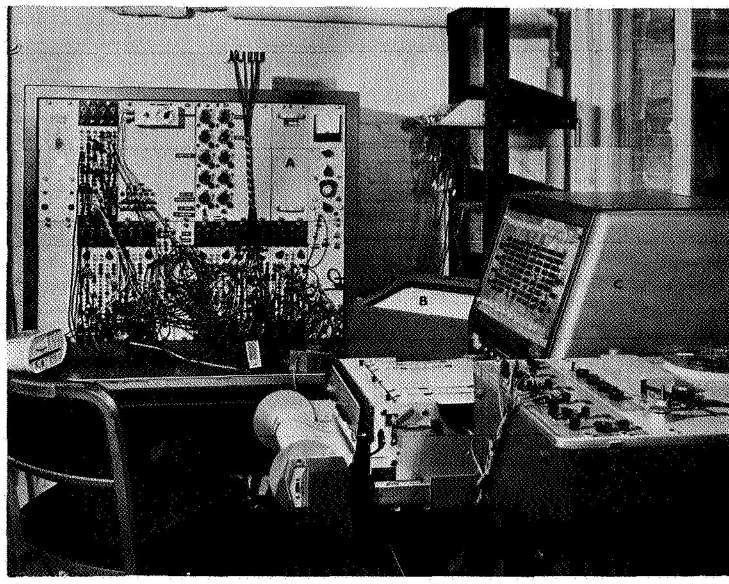

Figure 3. Illustration of Analog Computer, X-Y Plotter, and Brush Pen Recorder Used by the Experimenter

Procedure. The forty subjects were run individually for 6 daily 30-minute sessions. There was a 24-hour delay between Sessions 1, 2, 3, and 4; a 48-hour delay between Sessions 4 and 5; and a 24-hour delay between Sessions 5 and 6. Each subject was run at approximately the same time each day. The first 5 days were devoted to training. Each subject performed 40 practice trials in each session according to the schedule required by the condition to which he was assigned.

After the five practice sessions, all groups performed in the blanked condition during the 40 test trials of Session 6. This session was administered in the same way as the practice sessions for the Blanked Group. All subjects received integrated-absolute-error scores and viewed graphic records after trials 10, 20, 30, and 40.

The subject was seated in a sound-proof booth with his eyes approximately 50 cm from the oscilloscope (hence 1 cm of target displacement corresponded to 1.41° of visual angle). At the beginning of the first session he received a brief orientation to the equipment, then standardized directions were read (see Appendix). A graph of the specified movement pattern (see Fig. 1) was shown, and he was informed that the objective of the experiment was to test his ability to learn to perform the specified pattern by moving the control device. At the beginning of each trial a brief interruption of the noise in the subject's earphones provided a warning signal 1 second before the target began to traverse the screen. He then completed the movement according to his instructions and waited for the terminal feedback from the experimenter concerning his error score. After the first day, at the beginning of each day's training session the experimenter reported the subject's mean error score for the 40 trials during the previous practice session, as well as the mean error score for all 8 subjects in his own training group.

CHAPTER 4

RESULTS

This chapter presents a comparison of performance among the various groups during the training and testing phases of the experiment. Performance was examined in terms of integrated-absolute-error scores and in terms of a more detailed performance criterion that attempted to separate out the precision of performance with respect to amplitude and timing accuracy.

Integrated error during the training phase. The main results of the experiment are summarized in Fig. 4 which presents the integrated-absolute-error

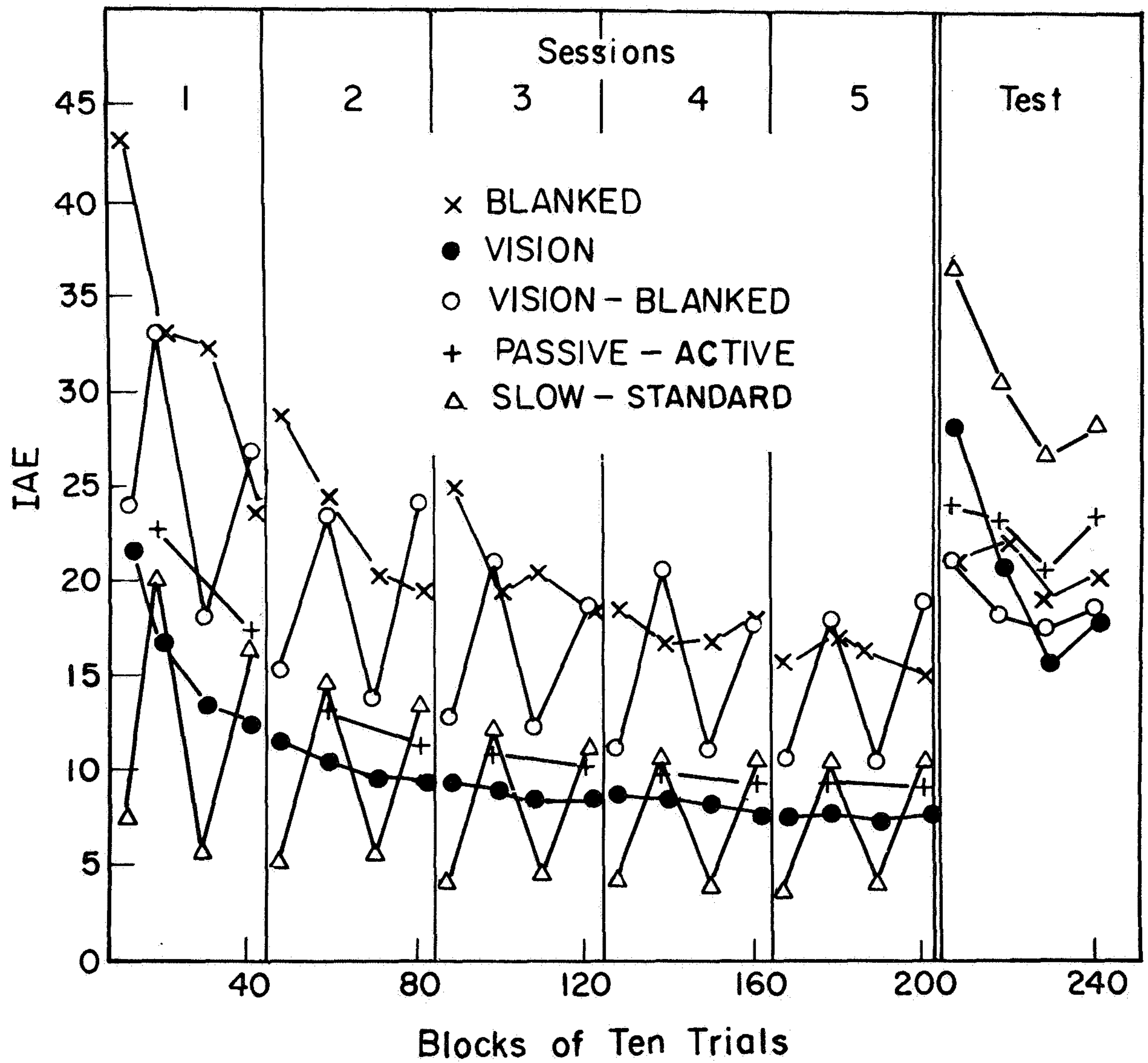

Figure 4. Mean Error Scores of Blocks of Ten Trials for Subjects in the Blanked, Vision, Vision-Blanked, Passive-Active, and Slow-Standard Groups during Training and Testing

scores for each condition averaged over blocks of 10 trials during training and subsequent testing. During the 5 training sessions the Blanked and Vision Groups may be considered as references against which to compare the performance of those groups that alternated between two conditions. It is clear that practice improved performance in all of the conditions studied; however, the pattern of improvement is distinctive for each group. Performance in the pursuit tracking task (Vision Group) was both better and less variable than performance in the blanked condition that required memory of the movement pattern. This result, however, is not terribly surprising in that these subjects had more information on which to base their performance.

Consider next the performance of the Vision-Blanked Group. On those trials in which this group performed in the blanked condition their performance, although variable, is substantially similar to that of the group that worked under the blanked condition for the entire training period. Evidently practice with vision proved to be as effective as practice on the pattern memory task for improving performance under the pattern memory condition. The converse appears not to be true for the Vision-Blanked Group. In order to make the vision trials of the Vision-Blanked Group overlay the vision trials of the pure Vision Group it is necessary to compare all 10 vision trials of the Vision-Blanked Group with the first 10 trials of the Vision Group. That it is possible to equate the groups in this way indicates that the practice which the Vision-Blanked Group received under the blanked condition was simply not contributing to the improvement of their performance under the vision condition. This suggests that in some way the skills required of the pursuit tracking task are more specialized than those required in the blanked, pattern memory task. Something must be learned in addition to what is learned under the blanked condition in order to perform under the vision condition.

A similar result can be observed for the Passive-Active Group. Collapsing the 10 active trials to correspond to the first 10 trials under the vision condition would result in a superposition of the two curves. Thus one may conclude that passive watching of the target moving across the screen contributed virtually nothing to the subject's ability to perform under the vision condition.

Turning now to the slow-standard condition the same trend was evident. Although performance on the slow speed task was intrinsically easier, and hence produced better performance, on those trials practiced at the standard speed, performance was equivalent to the vision task in the vision-blanked condition and to the active task in the passive-active condition. Nothing relevant to the performance of the pursuit tracking task at the standard speed appears to have been contributed by practice at the slow speed.

Performance on the Blanked Criterion Test

Consider next performance of the various groups when they were required to perform the pattern memory criterion test (blanked condition) during the sixth session.

When the criterion test was administered to all subjects, all groups increased in mean error scores. The increase in error scores for the Blanked Group was not expected since this group had had no change in procedure from training to testing. However, a "t" test of the error scores during the last ten trials of the practice session and the error scores of the first ten trials of the criterion test revealed that the change in error scores for the Blanked Group was not significant.

Aside from this observation, the character of the results shown in Fig. 4 for the criterion test may be summarized by three trends. The Blanked, Vision-Blanked, and Passive-Active Groups are clustered close together. The Vision Group starts out worse than these groups and showed rapid improvement in practice during the criterion test until after 30 trials they were performing slightly better than the other three groups. The Slow-Standard Group improved substantially during the testing phase; however, they were uniformly worse than the other four groups.

A test of homogeneity of variance failed to reject the hypothesis that the variances obtained during the criterion test were from the same population. Therefore, a two-way analysis of variance of groups by blocks of ten trials (Winer, 1962, p. 298) was performed to determine if the differences among the mean error scores of the five groups were significant. The data used in the analysis of variance were the error scores of each subject during each of the forty trials of the criterion test. Table 2 presents the summary of the analysis.

Table 2

ANALYSIS OF VARIANCE FOR IAE SCORES OF ALL SUBJECTS OBTAINED DURING THE CRITERION TEST

Source of Variation	SS	df	MS	F
Between Subjects	9727.35	39		
A (Groups)	9757.06	4	689.26	3.46* .05
Subjects within groups	6970.29	35	199.15	
Within Subjects	13214.54	120		
B (Trials)	1135.60	3	378.53	3.66**.05
AB	1226.04	12	102.17	
B x Subjects within groups	10852.90	105	103.36	

*F .95 (4, 35) = 2.65

**F .95 (3, 105) = 2.71

The Newman-Keuls method (Winer, 1962, p. 82) was used to test the differences between the means of the five groups. The results of this test showed that the mean error score for the Slow-Standard Group was significantly different from the mean error scores of the other four groups (see Table 3). The other groups

(Vision-Blanked, Vision, Blanked, and Passive-Active) did not differ significantly from each other.

Table 3

NEWMAN-KEULS TEST FOR DIFFERENCES BETWEEN MEANS OF FIVE GROUPS DURING THE CRITERION TEST

	VISION-BLANKED	VISION	BLANKED	PASSIVE-ACTIVE	SLOW-STANDARD
Ordered means:	18.76	20.66	20.77	22.96	30.62
VISION-BLANKED	-	1.90	2.01	4.20	11.86*
VISION		-	.11	2.30	9.96*
BLANKED			-	2.19	9.85*
PASSIVE-ACTIVE				-	7.66*
SLOW-STANDARD					-

*Significant at 5 percent level

The subjects in the Slow-Standard Group differed the largest amount during the first block of ten trials from the other groups (see Fig. 4). This difference, although not as large, held true for trial blocks two, three, and four.

A Newman-Keuls test was also performed on the mean of all groups combined for each block of ten trials to determine if there was a significant difference in performance from trial block to trial block. Table 4 presents the data from this test.

As can be seen in Table 4, there was a significant difference in the mean error scores of the groups between the first and the third blocks of ten trials. Inspection of Fig. 4 shows that the Slow-Standard and Vision Groups had greater changes in mean error scores from trial blocks one to three than the other groups and were probably responsible for the significant difference obtained.

Table 4

NEWMAN-KEULS TEST FOR DIFFERENCES BETWEEN FOUR BLOCKS OF TEN TRIALS EACH DURING CRITERION TEST

	Block 3	Block 4	Block 2	Block 1
Ordered Means:	20.00	21.40	23.03	26.30
Block 3	-	1.40	3.03	6.30*
Block 4		-	1.63	4.90
Block 2			-	3.27
Block 1				-

*Significant at the five percent level

Trial-by-Trial Performance of the Training Groups

Fig. 5 and 6 present the trial-by-trial average scores during training and testing for the various conditions. These figures further emphasize the greater variability of performance of the Blanked and Vision-Blanked Groups performing under the blanked condition, and for all groups when they were tested under the blanked condition. Two other features of the trial-by-trial data should be pointed out.

First, it is possible to observe the effect on performance of leaving the booth, viewing the graphic record of performance on the last previous trial, and then returning to further practice. Since this procedure involved a period of rest outside the booth as well as viewing the graphic records, it is not possible to separate out these two effects. However, during the first day of practice it appears that the subjects in the Blanked Group benefitted substantially from feedback presented in this way, while the subjects in the Vision Group showed no systematic effects of viewing graphic records. For the Blanked Group a t-test revealed that there was a significant difference at the 0.05 level between error scores before and after graph inspection during the first session. A similar t-test for the subjects in the Vision Group revealed no significant difference.

The most reasonable interpretation of the differential usefulness of viewing graphic records as a form of terminal feedback is that the concurrent intrinsic visual feedback provided to the Vision Group makes the subsequent graphic record viewing superfluous, whereas this mode of feedback is of primary importance to the Blanked Group. This interpretation is further supported by the data for the Vision Group during the testing phase in which they were performing under the blanked condition. You will note that during the first testing blocks, the Vision Group benefitted substantially from reading graphic

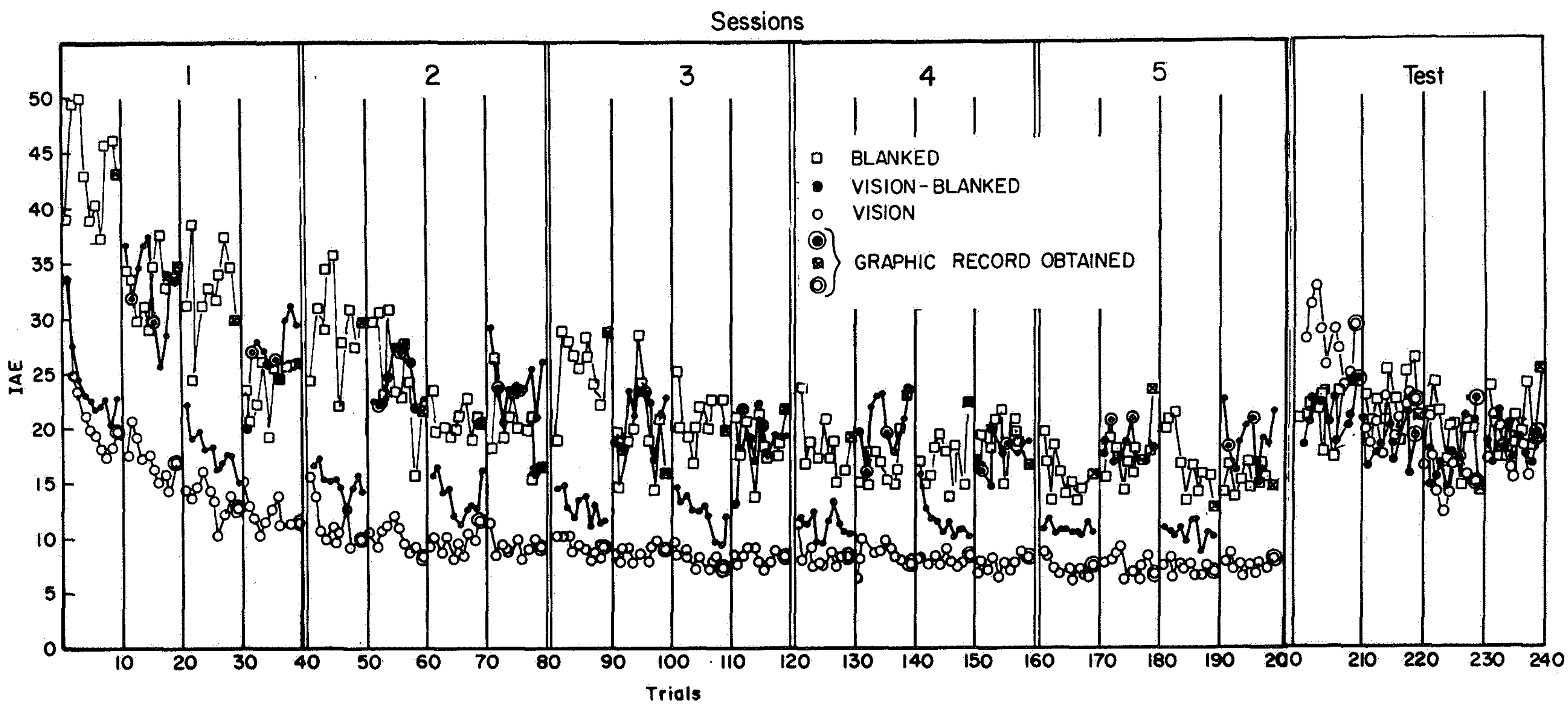

Figure 5. Mean Error Scores during Training and Testing for Subjects in the Blanked, Vision-Blanked, and Vision Groups (Circled trials indicate that graphic records were obtained.)

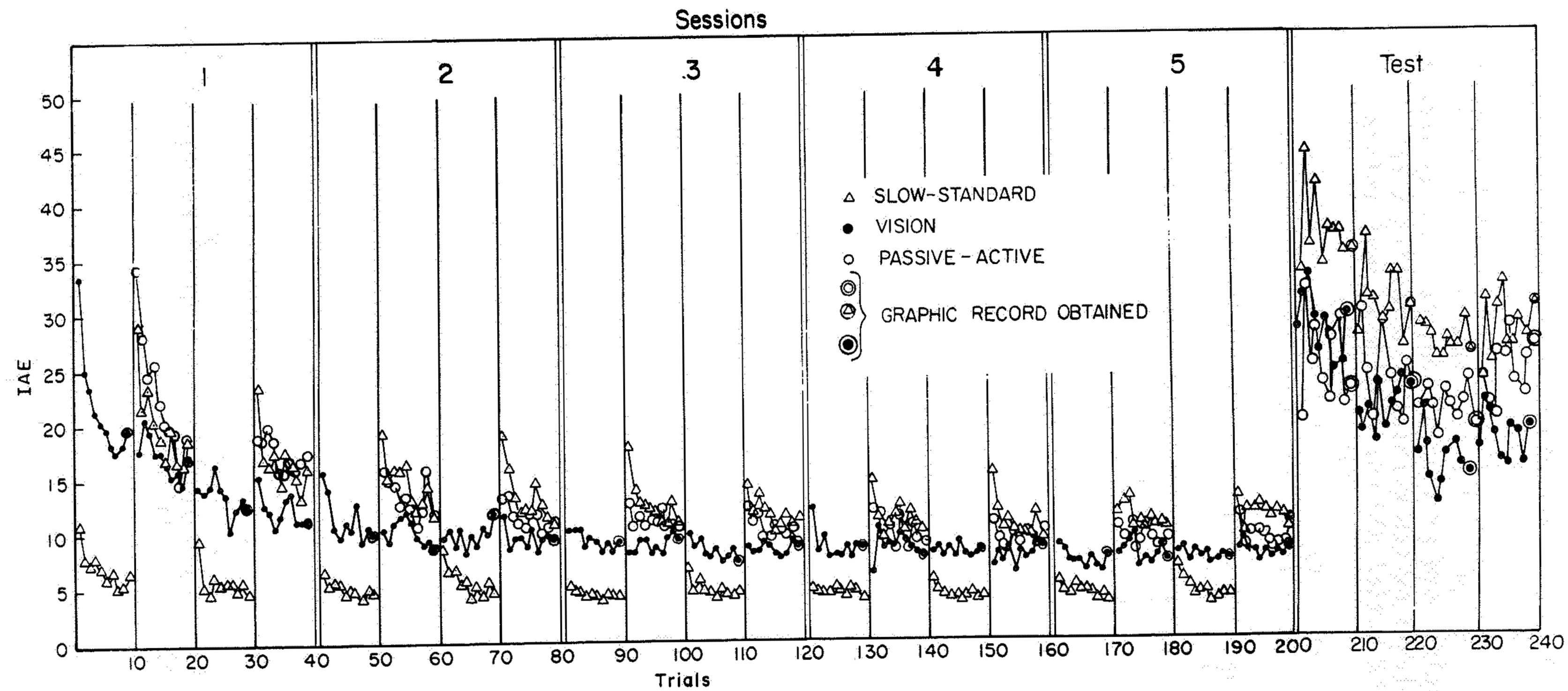

Figure 6. Mean Error Scores during Training and Testing for Subjects in the Slow-Standard, Passive-Active, and Vision Groups. (Circled trials indicate that graphic records were obtained.)

records. The fact that the Vision Group did not benefit from this treatment during the training phase suggests that the graphic records themselves were important and that the improvement in performance was not simply a result of leaving the test booth for a brief rest. When deprived of visual feedback, and terminal graphic results were available, subjects quickly took advantage of the new mode and were able to switch methods of obtaining feedback with relative ease even though the second method did not provide as much information as the first.

Second, while the trial-by-trial learning curve of the Vision Group is relatively continuous, this is in contrast to the performance of the Slow-Standard Group. Every time this group transitioned from slow to standard or from standard to slow speed performance there was evidence of substantial loss in performance over the level that was attained at the end of the previous block of practice under that condition. There appears to be a requirement for relearning that is especially noticeable after transfer from slow speed to standard speed. This loss in performance could be attributed to a warm-up effect, but is more likely the result of substantial negative transfer between the two conditions. It persists all the way through Session Four.

Analysis of Amplitude and Timing Errors.

In order to obtain more detailed information about the specific kinds of errors subjects made while performing the movement pattern, selected graphic records from the X-Y plotter were scored using a technique suggested by Poulton (1962). The three distinctive peaks in the movement pattern were singled out and the position of the subject's output relative to the desired output were compared in terms of position and timing accuracy. Fig. 7 illustrates the two types of errors that were measured. A timing error was considered to be one in which the subject was in the right place, but at the wrong time. A timing error could be represented as either a lead or a lag. A position error occurred when the peak amplitude was either too large (overshoot) or too small (undershoot). Although not shown in Fig. 7 both position errors and timing errors could occur at the same peak.

The position and timing errors were analyzed in two ways. In order to indicate the average accuracy in position and time, the error magnitudes were averaged without regard to sign. In order to look for systematic biases in the performance of the movement, that is, whether the subjects were predominately leading or lagging in time, or overshooting or undershooting in position, the average was recomputed, taking into account both magnitude and sign of the error. These two error scores were called, respectively, absolute errors and directional errors.

Four graphic records from the X-Y plotter data were selected for each subject per session for this further analysis. The four graphs were records of the 10th, 20th, 30th, and 40th trials for each subject in the Vision, Blanked, Passive-Active, and Slow-Standard Groups. Records of the 12th, 16th, 32nd, and 36th trial were used in the analysis for subjects in the Vision-Blanked Group since these were the only ones available.

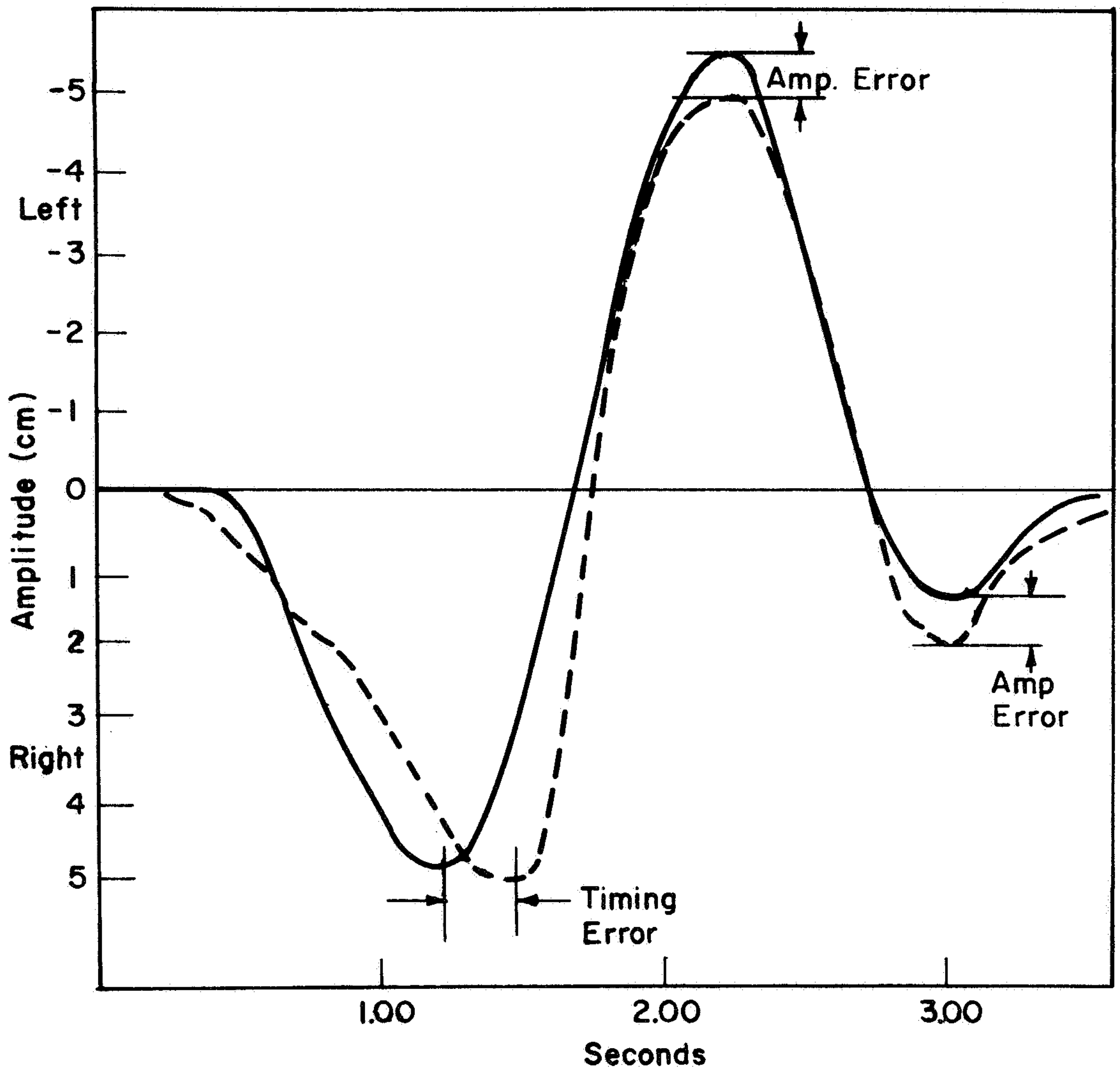

Figure 7. Sample Graphic Record (of subject:ER during Session 1 under the Blanked Condition)

Position errors. The results obtained from measuring the absolute position errors can be seen in Fig. 8 as a function of training groups and sessions of practice. As might be expected, during the first five sessions subjects who used some form of visual feedback (Vision, Slow-Standard, and Passive-Active Groups) performed better than did subjects who did not have access to visual error information. During the testing phase all groups' performance was worse than during the practice sessions except the Blanked Group.

Although the performance of the Slow-Standard Group was the worst in absolute position error duing the criterion test, their performance was not significantly different from the absolute position error scores of the other groups.

No categorical generalization was possible from the data on directional position errors, but there was a general tendency for those subjects who

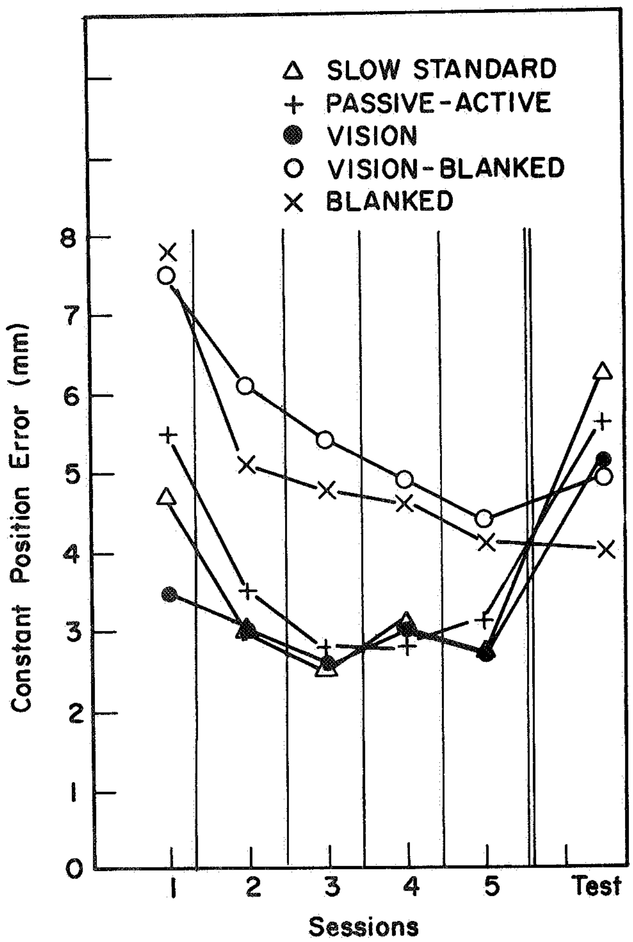

Figure 8. Constant Position Errors Taken from Graphic Records

were trained with visual error information to undershoot the peaks and for those who practiced under the blanked condition to overshoot. Fig. 9 presents the data for each peak. During the criterion test the subjects in all five groups on the average overshot the first peak. The error scores for peaks two and three reflect more undershooting errors.

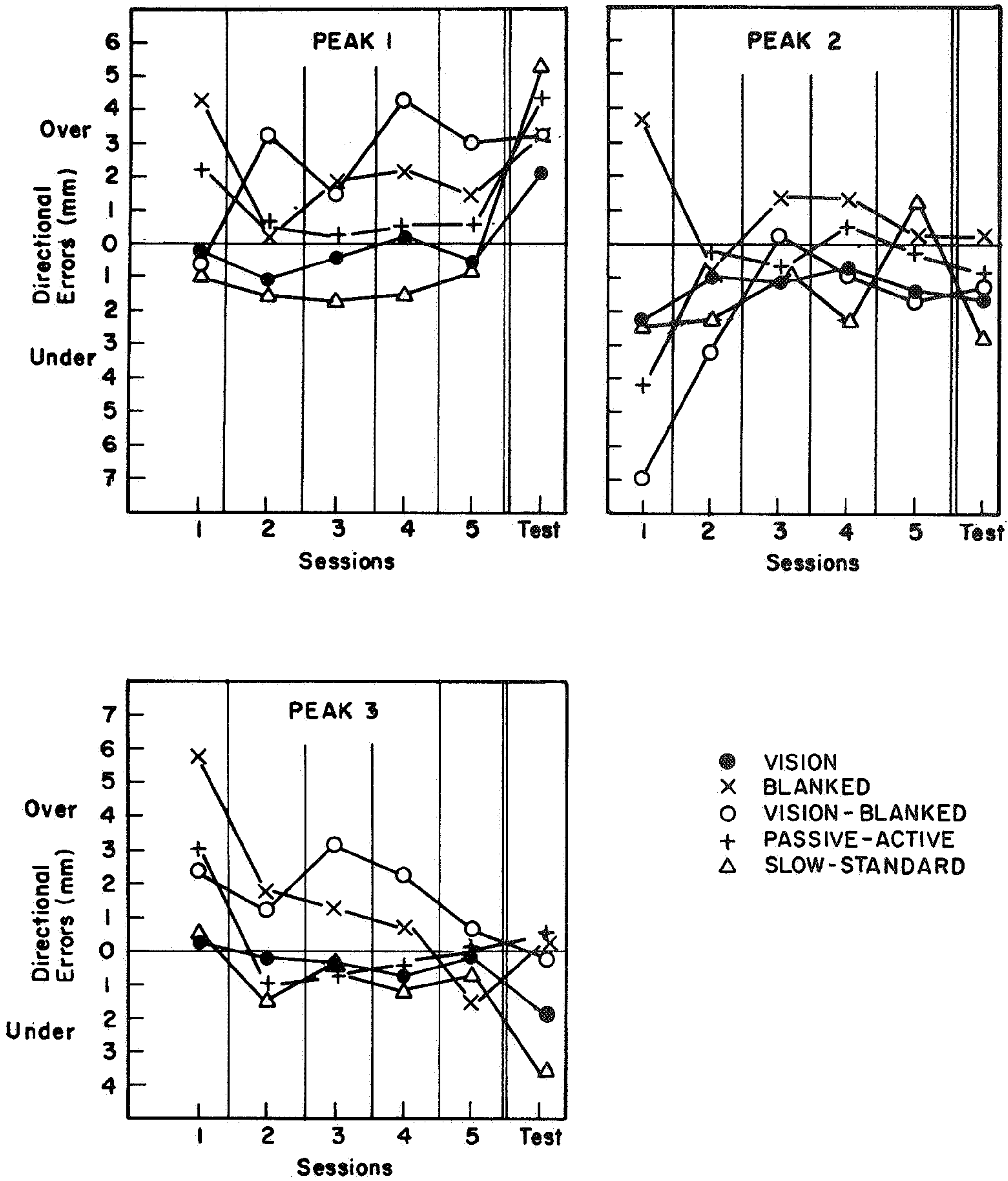

Figure 9. Directional Position Errors for Three Peaks of Graphic Records

Timing errors. The analysis of absolute timing accuracy shown in Fig. 10 indicates the trend already familiar from the results just described. The groups who did not receive visual feedback during training performed more poorly with respect to timing accuracy. Examination of absolute timing errors during the criterion test indicated that the subjects in the Slow-Standard Group had higher absolute timing error scores than the subjects in the other four groups.

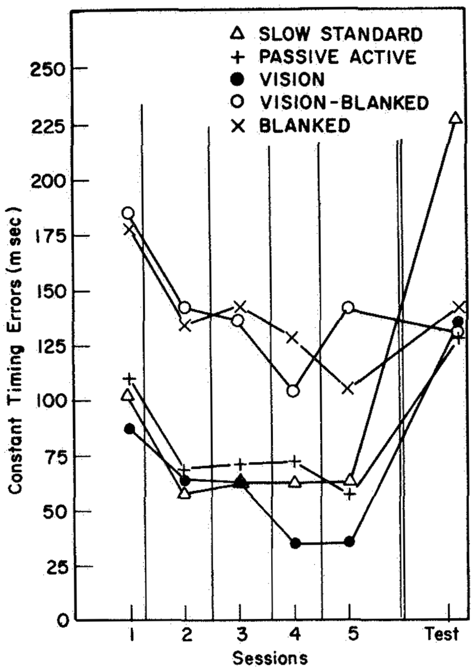

Figure 10. Constant Timing Errors from Graphic Records

A one-way analysis of variance (Table 5) indicated that the differences in absolute timing errors which occurred during the performance of the criterion test were significant at the 0.05 level. A subsequent t-test between the means

Table 5

ANALYSIS OF VARIANCE FOR CONSTANT TIMING ERROR SCORES

DURING THE CRITERION TEST

Source of Variation	SS	df	MS	F
Groups	71.00	4	17.75	2.71*
Error	230.00	35	6.58	

*F .95 (4, 35) = 2.64

revealed that the error scores for the Slow-Standard Group differed significantly from the error scores of the other groups. This result, coupled with the previous finding that the amplitude errors for the subjects in the Slow-Standard Group were not significantly different, suggests that it was the timing requirements of the task that the Slow-Standard Group subjects were not able to master as well.

All groups displayed an increase in absolute timing error score from the 5th to the Test Session. This rise in timing errors for the Blanked Group that was not observed for the analysis of amplitude errors provides some indication that the unexpected rise in overall integrated-absolute-error performance for the Blanked Group was due to their loss of timing accuracy.

The analysis of directional timing errors (see Fig. 11) produced two generalizations. With respect to peak 1 the groups who received visual concurrent feedback consistently lagged the input pattern during the first 5 training sessions while those who did not receive visual error information were consistently leading. Referring back to Fig. 1, the jog in the amplitude pattern just prior to the first peak probably accounts for this result. The subjects who were not receiving visual feedback failed to take account of this jog and thus responded early to the first peak while those who were receiving visual feedback tended to overcompensate for this jog.

The second generalization concerns the Slow-Standard Group. This group consistently led the position of each peak during the criterion test, although in most cases they were either well synchronized or lagging during the training sessions. This result simply provides one more indication that the subjects in the Slow-Standard Group were unable to adjust to the timing requirements of the pattern especially during the testing phase.

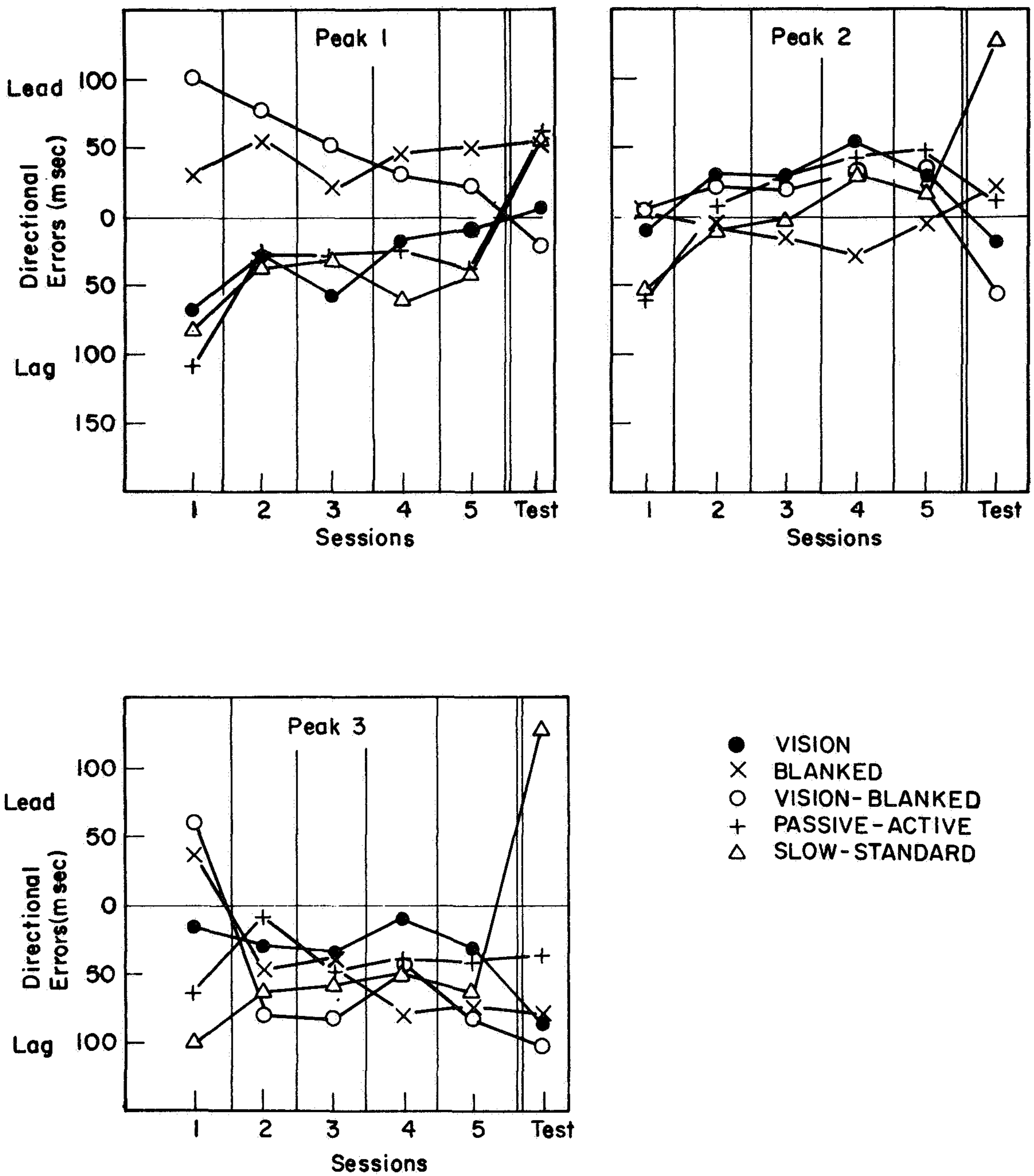

Figure 11. Directional Timing Errors for Three Peaks of Graphic Records

CHAPTER 5

DISCUSSION AND CONCLUSIONS

The central question of this research concerned the development of effective training techniques for performance of a motion pattern that is defined for the subject in space and time but for which visual feedback about the error being produced is not provided. Both the training and testing results of this experiment had some bearing on this question.

Since the simplest possible training procedure, under most circumstances, would be merely to practice the task for which the subjects were being trained, all groups' performance should be compared to that of the Blanked Group. With this group as a standrad, the results of this experiment point to several training methods that are not substantially superior to training under the blanked condition.

Consider first the slow-standard condition. The alternation of blocks of 10 trials between pursuit tracking of the movement pattern at two different speeds was shown to produce significantly worse performance under the test condition than the other techniques tested. A detailed analysis revealed that it was the timing aspects of the pattern that were inadequately learned under this condition. The slow-standard training technique resembles in some respects the procedure in which the student is requested to run through the movement pattern slowly in order to get the idea, and then practice it at the standard speed. Although there still may be some advantage to practicing the movement pattern slowly very early in training, especially if the movement pattern is complex or requires coordinated movements in several dimensions, these data indicate that alternate practice at slow and standard speeds throughout practice was not an effective technique for learning the criterion task. Comparison of the slow-standard condition with the pursuit tracking condition (Vision Group) during training indicates that the slow speed practice also was contributing very little to the performance of the pursuit tracking task per se.

The test performance of the Passive-Active Group was not significantly different from that of the Blanked Group. This training technique resembles one in which subjects alternate between active tracking and passive demonstration of the movement pattern. Considering that they only had half as much actual practice at the task, it is somewhat surprising that their test performance is as good as it is. It is clear from the training sessions that their passive watching trials contributed nothing to their training for performance of the pursuit tracking task but the experiment is not sufficiently precise to tell whether their criterion test performance benefitted from the passive watching trials or whether half as many trials of practice at the pursuit tracking task were sufficient to produce the quality of performance exhibited on the criterion test. While one cannot rule out the usefulness of passive demonstration as a training technique, it did not produce superior performance to that of the Blanked Group that was trained on the actual task to be performed. It is also possible that different results would have been obtained if a group had been trained under a "Passive-Blanked Condition" in which they alternated 10 trial blocks between the blanked condition requiring pattern memory and the passive demonstration condition.

Perhaps the most interesting results were obtained from the Vision-Blanked Group. While their performance on the Criterion Test was not significantly different from the pure Blanked Group, their training performance indicates an interesting asymmetry between the blanked and vision conditions. It appears that practice under the pursuit tracking condition was as effective as blanked practice for performing the blanked task. This may be observed in Fig. 4 in which the data points for the blanked condition and the blanked trials of the vision-blanked condition overlay each other quite regularly. However, the converse is not true. The vision trials of the Vision-Blanked Group are consistently poorer than those of the pure Vision Group. It appears that practice under the blanked condition did not contribute to improved performance under the pursuit tracking condition. This result suggests that something more is required in order to perform the pursuit tracking task than is required to reproduce a movement pattern on the basis of memory and proprioceptive feedback alone. This vision-blanked condition has no traditional counterpart in the practical training for skills. It and the vision condition were studied because they were thought to have potential for such training. However, under the conditions studied here, the vision-blanked condition did not produce significantly superior performance.

Finally, consider the vision technique in which training was administered as a pursuit tracking task. As was pointed out in Chapter 2, this task compared closely with one of the conditions administered by Gordon (1959), and the data are quite similar to his results. Immediately after transfer, performance was substantially worse than in the blanked condition. However, continued practice produced large improvement in a short period of time, resulting in performance somewhat but not significantly superior to the blanked condition. Evidently the addition of concurrent visual feedback did not serve to enhance criterion test performance for which that feedback was not available, at least for the conditions studied here.

Summary

In summary, ground has been broken for the exploration of improved training techniques for performance of programmed movement patterns based on enhanced feedback of the movement requirements. Although none of the feedback methods employed produced significantly better criterion test performance, the trend for the group that practiced the pursuit tracking task was in the right direction. In addition, it was possible to reject as inferior the use of a mixture of slow and standard speed tracking practice.

It is clear that rote application of routine training methods fails to produce the desired training results. It is necessary to consider carefully the compatibility of the task requirements with possible training methods to pick a method that will meet the required training goals for each task.

It seems unreasonable that there are not, in general, feedback augmentation techniques that would improve training efficiency for a task in which a movement pattern must be produced. In light of the results presented here, a likely hypothesis is that the stage during training at which augmented feedback is introduced may be important. The results reviewed in Chapter 2 suggested that reliance on proprioceptive feedback develops relatively late in practice. Perhaps the training techniques should be designed to take advantage of that fact. The relatively rapid improvement in performance of the Vision Group during the criterion test phase is suggestive of such a result. If the testing session under the blanked condition had continued for more than 40 trials, the Vision Group might have continued to improve at a more rapid rate than that of the Blanked Group. Of course, it is also possible that other means of providing augmented feedback will be more effective than those tested here.

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APPENDIX

DIRECTIONS READ TO SUBJECTS

ALL SUBJECTS - FIRST SESSION

The purpose of this experiment is to determine how quickly and how well you can learn a specified arm movement. The movement when pictured on graph paper looks like this (Figure 1 was shown to the subjects.).

Your objective is to move your arm in such a way that you reproduce the pattern depicted in this drawing. If I move my arm like this (the movement was demonstrated), I'm doing the movement.

SUBJECTS IN VISION GROUP

In order to help you learn this movement, a target will move across the screen. (Turn on apparatus and let subject watch the target traverse the screen.) This control device moves these two dots which are called a cursor. By moving the control device you can superimpose the dots over the target. If you keep them together you will learn the required movement.

The pattern will always be the same. Each time you try the movement your path and the desired path will be recorded on a graph. This way we can determine how well you do.

As you learn the movement pattern, try to think how the movement feels. Eventually we want to see how well you can perform the movement under a blanked condition or without the aid of the target going across the screen.

After each trial I will tell you a score. The lower the score, the better you are doing. Also, I will graph every tenth trial. After ten trials are up come out of the booth and look at your graphic record. This will help you learn the movement.

SUBJECTS IN THE BLANKED GROUP

In order to help you learn the movement I want you to watch me perform the movement pattern several times. (Experimenter performs movement.) The pattern is always the same. To help you start the pattern properly, a dot or target lights up on the screen and begins to move across the screen to the right. When the control device is moved, the two dots or cursor moves. The object is to superimpose the two dots over the target and to keep them together until the screen blanks out, and then complete the pattern as best you can. Watch me as I do the pattern again. Now once more. The total time for the pattern is approximately 4 seconds.

Each time you try the movement your path and the desired path will be recorded on a graph. This way we can determine how well you do. Aften ten trials, come out of the booth and I'll show you your graphed movement and the desired movement which will help you see how you are doing. Also, after each trial I will tell you a score. The lower the score, the better you are doing.

In order to further give you an idea of what the pattern looks like I want you to watch the target traverse the screen five times. Do not move the control device, but watch and try to remember what the pattern is.

SUBJECTS IN VISION-BLANKED GROUP

In order to help you learn this movement, a target will move across this screen. (Turn on apparatus and let subject watch the target traverse the screen.) This control device moves these two dots. By moving the control device you can superimpose the dots on the target. If you keep them together you will learn the required movement.

You will practice in blocks of ten trials under two conditions for a total of forty trials per day. Your objective is to track the target or to superimpose the cursor over the target. The second ten trials will be done under what is termed a blanked condition. During the blanked condition the target will start and begin to move across the screen to the right. When the target gets about here (point on screen) both the target and the cursor will blank out. Your objective is to complete the pattern as best you can. The pattern is the same as that which you have practiced under the lighted conditions. (Turn on apparatus and let subject watch both conditions.) After completing ten trials under this condition you will go back to ten trials under the visual condition, and then ten trials under the blanked condition.

Also, during the blanked condition I will record a graph of your movement on the second and sixth trial of every ten trial block. At the end of the second and sixth trials come out of the booth and I will show you your graph of the previous trial. This may help you learn the movement pattern.

For several days you will practice this movement under the conditions I have just outlined. After several days of practice you will then have one complete session under the blanked condition. During this session we want to see how well you can perform the movement relying on feel and memory.

SUBJECTS IN THE PASSIVE-ACTIVE GROUP

For several sessions you will practice the arm movement by seeing the target go across the screen, and by moving the control device and tracking the target. You will practice in blocks of ten trials. For the first ten trials you will watch the target go across the screen. During the next ten trials you will practice the movement by moving the control device and superimposing the dots or cursor over the target, then you will go back to watching for ten trials, and then tracking for the last ten trials. Each session consists of forty trials. (Turn on apparatus and let subject watch the target traverse the screen.)

As you learn the movement pattern it is important that you try to remember how the pattern feels. Toward the end of this experiment, after several days of practice, you will perform the movement without the aid of the target going across the screen.

SUBJECTS IN SLOW-STANDARD GROUP

In order to help you learn the movement a target will move across this screen at a slower speed than that of the standard movement. For several sessions you will practice the arm movement by alternating blocks of ten trials at two different speeds. This is the slow speed (turn on apparatus). This is the regular speed (turn on apparatus). For the first ten trials the target will go at the slow speed, then for the next ten trials the target will go at the standard speed, then back to slow, and then ten standard. Each session will consist of forty trials. As you practice, your objective will be to move this control device which in turn moves these two dots called a cursor, and then superimpose the cursor over the target. If you keep them together you will learn the movement.

As you learn the movement pattern it is important that you try to remember how the pattern feels. Towards the end of the experiment, after several days of practice, we want to see how well you can perform the movement without the aid of the target going across the screen.

ALL SUBJECTS - FIRST SESSION

Let us go through the procedure step by step:

1. Sit down at the control device with your right hand on the control. Always keep you entire hand on the control handle. Never vary this hand position. Keep you entire arm resting on the control device. When you move the control to the right the cursor will go to the right and vice versa.

2. Hold up the earphones to your ear. Do you hear a noise in the earphones that sounds like a waterfall? When this noise is interrupted, the movement of the target will start approximately one second later. Each trial takes approximately four seconds at the standard speed to complete. I can also communicate to you through the earphones. When you talk I can hear you outside the compartment through this intercom system (point out intercom).

3. Now put on the earphones. I will shut the door and talk to you through the earphones.

4. VISION group: Remember after each trial I will tell you a score. The lower the score the better you are doing. Also, after ten trials are up I will inform you so you can come out of the booth and see a graph of your tenth trial. Do you have any questions?

BLANKED group: Watch now as the target goes across the screen. It will not blank out for these five watching trials. Do not move the control device during these five trials. Now we will start the blanked condition. That is, the target and cursor will start to move to the right, and then blank out; your objective is to complete the pattern. I will tell you a score after each trial, the lower the score the better. After ten trials are up, I will tell you, and you can come out and see the graph to see how well you are doing. Do you have any questions?

VISION-BLANKED group: At the end of each trial I will tell you a score. The score indicates how well you are on a position. The lower the score the better. The first ten trials will be with vision. I will tell you when ten trials have been completed and you will start the blanked condition. At the end of the second and sixth trials of the blanked condition I will inform you so that you can come out of the booth and look at your graphic record. Do you have any questions?

PASSIVE-ACTIVE group: After each trial I will tell you a score. The score is determined by how well you keep the cursor over the target. The lower the score the better you are doing. Of course, during the watching trials there will be no score. I will tell you when ten trials of watching have been completed and will instruct you to begin holding the control device so that you can track the target. During the ten trials when you watch do not hold the control device. Do you have any questions?

SLOW-STANDARD group: After each trial I will tell you a score. The score is determined by how well you keep the cursor over the target. The lower the score the better you are doing. Remember you objective is to learn the arm movement pattern so that you can reproduce it under the blanked condition at the standard speed. Do you have any questions?

ALL GROUPS - SECOND, THIRD, FOURTH, AND FIFTH SESSIONS

Your average score for yesterday's practice was ______. The average score of all the subjects in your group was ______.

BLANKED GROUP - SECOND, THIRD, FOURTH, AND FIFTH SESSIONS

Look at the graph again and try to picture the movement.

ALL GROUPS EXCEPT BLANKED - SECOND, THIRD, FOURTH, AND FIFTH SESSIONS

Remember that you will eventually be asked to reproduce the movement pattern without the aid of the target going across the screen. That is, the target and cursor will start to traverse the screen to the right. They will both blank out about 0.5 seconds later. Your objective at that time will be to complete the movement pattern.

ALL GROUPS EXCEPT BLANKED - SIXTH SESSION

Today we will do the blanked condition. Under this condition the target will start to move exactly as it has done during the practice sessions. However, 0.5 seconds later the target and the cursor lights will blank out. Your objective is to complete the movement pattern as best you can. Remember to try and reproduce the same pattern you have been practicing under the lighted conditions. I will tell you a score after each trial to inform you as to how well you did. Also, I will graph the tenth, twentieth, thirtieth, and fortieth trials. After a ten trial block of practice, you will come out of the booth and see this graphic record. This may help you to perform the movement pattern. Do you have any questions?

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