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PERIPHERAL AND CENTRAL INVOLVEMENT IN KINESTHETIC SHORT-TERM MEMORY

by

© JOHN HENRY SALMELA

A THESIS
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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Peripheral and Central Involvement in Kinesthetic Short-term Memory" submitted by John Henry Salmela in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

The purpose of this series of studies was to determine, across a wide variety of experimental tasks, the nature of the movement information that was being used in a motor STM paradigm. There were six factors of experimental interest: information load, axis of movement, recall delay, type of end point, method of movement and recall consistency. The experimental task involved subjects manipulating a freely moving joystick to establish a number of positions, and to reproduce them sometime later. The dependent variables were measures of absolute, directional and variability accuracy between the criterion and recall trials.

The experimental design was a treatment by subjects, factorial design with repeated measures and five replications per subject. The basic statistical method used to analyse the data was analysis of variance.

It was found that:

1. Unconstrained responses seemed to be based upon efferent information available to the performer, rather than the peripheral information that resulted from the movement. The central form of response information

was resistant to spontaneous decay and was usable for accurate multiple recalls.

2. Constrained responses made to afferent kinesthetic information tended to be less accurate than those made from efferent information.

3. Recall accuracy was an inverse function of memory load.

ACKNOWLEDGEMENTS

I have
the feeling of nearing now
a destination

And the mounting in me
is measured
by the sudden realization
that I don't remember
passing a halfway mark*

I would like to thank my advisor, Dr. Bob Wilberg, for allowing me and his other students to discover more of their own particular reality-- to "keep pushing away at the margins and searching for the truth, whatever."*

I also appreciate the time and the effort given me by my examining committee of Dr. Peter L. Lindsay, Dr. Willie N. Runquist, Dr. W. D. Smith, Dr. Al Dodds, and Dr. Bert W. Taylor, all of the University of Alberta. I would also like to thank Dr. Joe R. Higgins of Teachers College, Columbia University, for serving as my external examiner.

My deepest feelings are also extended to my co-worker and wife, Sheila, whose efforts far exceeded the line of duty.

*from Poems of Red Lane. Vancouver, Very Stone House, 1968.

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CHAPTER 1

STATEMENT OF THE PROBLEM

Introduction

One approach to understanding how man performs physical skills is to consider him as a limited channel processor of information, made up of components which can describe his behavior within well defined limits (Fitts and Posner, 1967). This approach has been used successfully for the prediction of human motor performance by analysing complex skills into functional units of known information loads. This task load is then considered in relation to the limitations of the sensory, processing, memory and effector components of the performer. The capacity of the performer to handle the information load in the task can conveniently be quantified by the reduction of uncertainty techniques provided by Information Theory.

One important component that describes the "present state of the performer" is short term memory (STM). STM has been described by Fitts and Posner (1967) as "... a system which loses information rapidly in the absence of sustained attention," after which the information either goes into permanent store or is lost from the system. STM can be considered a buffer zone or work space where environmental stimuli (input) or information from long term memory (LTM) can either be held in an overflow mechanism, or until there is sufficient information upon which to act (Posner, 1967b). The STM paradigm has been extensively researched using verbal and/or visual inputs (Posner, 1963; Postman, 1964; Adams, 1967).

More recently, researchers have used kinesthetic or movement-produced stimuli as input in STM paradigms in an attempt to discover common memory mechanisms between the kinesthetic and the visual/verbal systems (Posner and Konick, 1966; Posner, 1967a). The assumption basic to this extension of STM research into the motor domain is that the sensory information from the kinesthetic receptors was of sufficient fidelity and meaningfulness that it could actually be used by the performer of skills.

Spurious conclusions as to the nature of motor memory could result if this assumption were not empirically verified. For example, the use of a movement system as a form of input and as the mode of output, along with instructions to the performer to respond, tended to produce an ambiguous experimental paradigm. The experimenter could not be certain whether the performer responded according to the input stimulus presented; or, independent of the stimulus to a set of responses that he was prepared to make at that time. Wilberg (1969b) stated that the movement dimension to which a subject attended, was at that time not known. Furthermore, the work of Taub and Berman (1968), in which all sources of sensory input were removed, demonstrated that animals could respond in complex motor routines in the absence of all peripheral information.

A wide variety of movement tasks are required of the performer of physical skills in the physical education setting. Yet the STM research for movement inputs has restricted itself to simple replacement accuracy tasks of low information loads. Using this research, the characteristics of the memory capacity for movements could not be generalized to anything but the simplest of skills. In the same way, inferences from data on the capacity of a performer to remember a single consonant could not describe the complexities of verbal behavior. The meaningful use of empirical findings necessitates the expansion of motor performance research into a broader frame of reference.

Purpose

The purpose of this series of studies was to systematically vary a wide range of movement constraints in a STM paradigm in an attempt to determine the nature of the information used by the performer.

Problems

Experiment I: The length and complexity of presentation lists have been found to be important variables in verbal/visual STM literature with most drastic performance changes evident when the memory capacity was exceeded (Posner, 1963). Length of movement (Pepper and Herman, 1970), as well as movement complexity for sub-memory span loads (Sharp, 1971; Wilberg and Sharp, 1970), has been found to be an important factor in kinesthetic STM. In this study, a two-dimensional movement task, incorporating from low to very high information loads, was used in a STM paradigm with a standard delay interval.

Experiment II: The question as to what information the performer has attended in a movement task has been difficult to determine. Overlearned motor responses, instead of the experimental stimuli presented by the experimenter, could be utilized by the performer. In this study experimenter-controlled movement patterns were used in an attempt to determine whether this type of information input varied recall accuracy across movement loads and delay of recall.

Experiment III: The accuracy of recall in movement tasks would seem to be affected by the types of physical restraints limiting the criterion movement. A "centralist" viewpoint in which the performer monitored central information, as presented by Taub and Berman (1968), would predict greater movement control for the recall of self-determined criterion movements than for recall of movements that were externally terminated. The orientation of the bulk of kinesthetic STM researchers who used simple replacement accuracy tasks with physical stops could be classified as "peripheralist" in that the performers were believed to use kinesthetic sensory information. In this study comparisons were made across movement loads and between the recall of externally-terminated and self-terminated criterion movements.

Experiments IV and V: The consideration that a subject in a kinesthetic STM experiment used a source of information other than that perceived peripherally might also be investigated by analysing the consistency of response(s) to an initial stimulus. Information from the periphery is usually considered to be susceptible to interference and decay (Pepper and Herman, 1970), while central LTM information is considered more resistant to forgetting (Konorski, 1967). In these studies response consistency to self-determined and environmentally-determined stimuli were examined across movement loads.

Definitions

Short-term Memory (STM): "A system which loses information rapidly in the absence of sustained attention.. (involving) about the first sixty seconds after presentation of a new stimulus. After that time, either the items are lost or they are transferred to a long-term memory system" (Fitts and Posner, 1967).

Kinesthesis (K): Operationally defined as that particular form of non-visual information generated by the gripping and moving of a joystick.

Efferent Information: Information from the central nervous system to the motor effectors available to the performer.

Afferent Information: Information from the peripheral nervous system from the sensory receptor available to the performer.

Movement Alignment Components: One dimensional movement components of two dimensional movements in the mid-frontal plane (Poulton, 1963).

Absolute Error (AE): The average unsigned difference in millimeters between a criterion movement trial and a recall movement trial.

Constant Error (CE): The average signed difference in millimeters between a criterion movement trial and a recall trial.

Variable Error (VE): The average variability (standard deviation) about the constant error.

Limitations of the Study

a. The Study is limited by the ability of the subjects (Ss) to follow the prescribed instruction for the duration of each experimental session.

b. The study is limited because there are only indirect ways of determining what type of information the subject was attending to.

Delimitations of the Study

a. The study is delimited by the sex, number, sampling and ages of the Ss.

b. The study is delimited by the accuracy and reliability of recording of the analog data and transcribing the data to a digital form.

CHAPTER 2

RELATED LITERATURE

One of the strengths of human performance theory research is that it attempts to analyse performance variables that explain phenomena which span a wide range of activities. Research that accomplishes this aim has been said by Wilberg (1969a) to have "theoretical meaningfulness," rather than "operational meaningfulness" which is unique only to each specific experimental situation. In this chapter relevant literature that applied directly to the research problem has been reviewed. There has also been an attempt to draw a thread through the kinesthetic STM literature in order to impart "theoretical meaningfulness" to this important component of human motor performance.

The initial review concerned the distinction between a peripheralist and a centralist viewpoint with regard to monitoring of movement information. Studies relating to storage codes of movement and visual information followed directly. A rationale for the use of dependent variables sensitive to changes in motor memory was then outlined. The final section reviewed motor performance literature dealing with a variety of movement tasks.

The Peripheralist Viewpoint

The concept of man being a limited channel processor of information, as outlined by Fitts and Posner (1967), states that the performer can transmit, reduce or create information. The bulk of human performance literature deals with the two former functions to the exclusion of the latter. In order that the operator transmit environmental information, it is necessary that this information is taken in through a sensory system, is operated upon by a central processor and is responded to by a motor output system. This approach could generally be referred to as a peripheralist view of the performer.

STM research in the verbal and visual domains, by the nature of the variables being studied, forced the S to attend the incoming information in the stimulus. Posner (1963) outlined this position clearly:

> A large number of psychological tasks involve the presentation of sequential information to the subject (S). In these tasks S is required to receive, process and store data for presentation in the response. If the task requires nearly complete representation of the stimulus in the response, then as the number of stimuli to be included increases or as the delay between stimulus and response gets longer, the memory requirement becomes a limiting factor in the correct completion of the task.

The use of a STM paradigm for the processing of kinesthetic information was therefore premised by the fact that the S used the incoming information from the kinesthetic receptors. It became extremely difficult, however, to determine how much "representation of the stimulus" the S used to respond when both the input and the output portions of the paradigm were movements.

Pepper and Herman (1970) presented a model of motor STM that integrated a great deal of divergent research in the area. The first assumption of their model of motor memory was stated:

> An accurate memory trace or representation of the intensity of extent of the criterion motor act is initially stored, but is subject to decay over time.

The consequences of such an assumption will be described subsequently, in the discussion of kinesthetic tasks. The fact that sensory information was accurately stored is basic to a peripheral point of view.

The Centralist Viewpoint

Central Representation of Movement: Recent considerations of "response images" (Hebb, 1968) and "ideomotor mechanisms" (Greenwald, 1970) as being mediators for the initiation and control of motor behavior had been outlined in the nineteenth century (James, 1890). This area of research considered the output rather than the input end of the information processing channel in the human performer. Response elaboration of often minimal information from the environment became a form of information creation from this orientation.

Konorski (1967) proposed a simple ideational unit or "gnostic unit" that was basic to perception, cognition and overt performance. Perception of learned movements occurred by the activation of the kinesthetic gnostic unit complex, based on efferent rather than afferent information. This executive area of the motor cortex caused a lower effector center to fire and carry out the action. An important aspect of Konorski's model was that a higher associative center perceived and modulated the motor plan while a lower center routinely carried out the detailed action.

Greenwald (1970) presented an "ideo-motor mechanism," similar to Konorski's gnostic unit, in which a central representation of the movement image was elicited by the anticipated sensory feedback of the response, rather than the afferent information itself. This could be considered a monitoring of the efferent information or of the outgoing motor plan.

Taub and Berman (1968) substantiated the use of central monitoring devices of movement information in their research on completely deafferented animals. They stated:

> Since the required information concerning the topology of their movements could not have been conveyed over peripheral pathways, it must have been provided by some central mechanism that does not involve the participation of the peripheral nervous system.

Their deafferented animals were still able to carry out complex motor functions in the absence of all sensory feedback.

Information Creation in Motor Performance: In the motor domain, the speculation of an information creation system may be useful, for, with a minimal information input, either from the periphery or from a higher central store, elaborate motor output can result. Vanderwolf (1969) presented neurophysiological evidence that the initiation of voluntary movements had physiological concomitants in the rhythmical activity in the hippocampus, but the well patterned motor output that occurred after the initiation did not. Brindley (1964) pointed to this same phenomenon when he stated that instructions from the forebrain, even if elaborated as much as possible, could not give sufficient information to the anterior horn of the spine to carry out the movement. Similarly, Glickman and Schiff (1967) pointed out that the proper ordering and elicitation of the movements occurred in the neocortex, but the detailed patterning occurred in the non-conscious brain stem.

Storage Codes in STM

Non-kinesthetic Tasks: The limited information processing capacity of the human performer prevents him from retaining, in either LTM or STM, all aspects of environmental stimuli when the information load is high. Rather, the information must be organized or coded along one of its prominent dimensions before it is stored. The experimental paradigm used to determine along which dimension coding takes place is one in which an interpolated task which is loaded along the relevant dimension is introduced between the criterion input trial and the recall trial. Interference with recall performance indicates that coding of the input occurred along the loaded dimension of the interpolated task.

Conrad (1964), Wickelgren (1965, 1966) and Sperling (1967) showed verbal STM to be coded along the dimension of acoustic similarity. Sperling systematically developed a STM model in which the verbal information could enter by way of the visual or acoustic system but was then rehearsed in an auditory store. Similarly, Baddeley (1964, 1966) showed that verbal LTM was coded along a semantic dimension.

In the visual domain, memory for simple forms was stated by Riley (1962) to be stored in the form of images while more complex visual input was shown by Haber (1964) to be most efficiently stored with verbal labels. Clarke

(1965) substantiated these findings by demonstrating the utility of storing complex forms by verbal labels and simpler forms as images. This interaction of the verbal and visual systems suggests that the two dimensions may be modulated by similar memory mechanisms. Pepper and Herman (1970) stated that "...the description of the verbal STM may be generalizable to visual items...but not necessarily to motor items."

Kinesthetic Tasks: In an attempt to discover common memory mechanisms between visual and kinesthetic STM systems, Posner and Konick (1966) discovered the reverse. Interpolated tasks affected the visual and not the kinesthetic recall, although both systems spontaneously lost information through decay. A later study by Posner (1967a) confirmed the earlier findings and showed that different storage codes were involved in the visual and kinesthetic systems; the former being an active one and the latter being a passive one. Kinesthetic information was believed to be stored as an image rather than with verbal labels because of the spontaneous decay over the unfilled interval. This indicated that the trace was in an unrehearsable form. The accuracy with which the responses were made also argued against the use of verbal labels. Similar findings were made by Boulter (1964) and by Adams and Dijkstra (1966).

In an attempt to discover along which dimension K information was coded, Wilberg and his associates completed a series of experiments varying the direction of replacement, ballistic pressure changes, constant weight loads, distance and constant torque in the common STM replacement paradigm (Hughes, 1969; McClements, 1969; Moyst, 1969; Wilberg, 1969b, respectively). In no case was the null hypothesis rejected. It was suggested by Wilberg (1969b) that kinesthesis might be undecodable.

Laabs (1971) extended Posner's (1967a) findings that visual and kinesthetic information was stored with different memory codes by separating confounding movement cues available to the performer. Differential recall of movements to locations in space and recall of movement distances occurred. Recall with reliable location cues showed similar interference effects to the recall of visual STM information in Posner's (1967a) study. Recall accuracy of movement distance was unaffected by interference effects. This latter finding was supported by Wilberg's (1969b) statement that the dimension along which kinesthesis is coded was not known.

The above findings failed to determine the relevant dimension that kinesthesis was coded along if location cues were made unreliable. One conclusion that may have been drawn was that the fidelity of distance information was not high and may not have been codable. This type of information therefore might not be stored in a STM system. In the face of this type of experimental task, the performer could revert to a centrally monitored response mode as outlined in an earlier section.

Dependent Variables in Motor STM Research

Fitts and Posner (1967) pointed out that in goal-oriented behavior the performer was often evaluated on "What he is doing" rather than on "What he is trying to do." The dependent variable or measure taken to evaluate performance must be well chosen if the nature of the investigation is to evaluate purposeful behavior by positive performance measures, rather than absolute performance by error scores.

Early research in motor STM (Adams and Dijkstra, 1966; Posner and Konick, 1966; Posner, 1967a) used algebraic error (AE) as a measurement of motor recall. Any discrepancy from the criterion movement, regardless of the direction or the consistency of the movement, was insensitively classified as an errorful performance.

Pepper and Herman's (1970) review article on motor STM resolved contradictory findings by selecting a dependent variable that was more sensitive to performance changes.

The use of constant error (CE) or signed error, allowed them to rectify conflicting findings with regard to memory trace decay and the effect of interpolated tasks. Measures of CE were sensitive, not only to the magnitude of discrepancies from the criterion movement, but also to the direction of these discrepancies. This gave a measure of the performer's "response biases."

Laabs (1971) demonstrated that the use of CE or AE scores alone could mask real changes in motor performance. He proposed the use of variable error (VE) scores which indicated the consistency of the CE scores. Laabs pointed out that when the variability of AE is small the following relationship is true:

$$AE = \sqrt{(CE)^2 + (VE)^2}$$

If only AE were used as a dependent variable, inverse changes in both CE and VE would show no net change. The use of CE alone, without the use of VE, could also lead to false conclusions because the performer may be more variable in his responses while the CE did not change. Similarly, a change in CE and no change in VE would point to experimental effects that could not be tested with less sensitive measures.

Motor STM and Movement Tasks

The type and quality of information used by the performer to reproduce movements cannot be determined unless a wide variety of movement tasks are investigated. In this section, the literature on a number of movement dimensions was reviewed.

Kinesthetic Load: The bulk of kinesthetic STM literature, a simple replacement accuracy task, involving either moving a linear slide (Stelmach, 1969, 1970) or rotating a handle (Norrie, 1968; Wilberg, 1969b) was used. Pepper and Herman (1970) found that the length of the movement task was critical to the selection of response strategies.

Wilberg and Sharp (1970) and Sharp (1971) investigated kinesthetic STM using a 2-dimensional movement task in which the information load could be varied. The information load, as defined by the number of movements to be remembered, was shown to cause a linear increase in the absolute error measures up to 8 movements. According to Miller's (1956) findings, the memory span across most dimensions is consistent at about 7 plus or minus 2 items. The above studies seemed, therefore, to have investigated movements within the range of the memory span. Although list length has been shown to be an important variable in verbal STM (McLane and Hoag, 1943; Anderson, 1960), supra-memory span loads have not been used in movement research.

End Point Control: Most kinesthetic STM research has used a physical stop to control the extent of the criterion movement (Posner, 1967a; Stelmach, 1969, 1970). Given that a performer can use the kinesthetic sensory information from a movement task, there would be no difference between the use of a physical end point or a self-terminated stop. Wilberg (1971), using absolute error as a dependent variable and a simple replacement accuracy task, found no difference in recall between the use of a physical stop, a self-terminated stop and stopping to a tone for the criterion trial.

Merton (1964) and Taub and Berman (1968), who reported accurate central monitoring of movement sequences, would predict that self-terminated criterion movements would be recalled more accurately than movements that were externally stopped.

Movement Consistency: Adams and Dijkstra (1966) found that the number of previous criterion responses made to an external stop was an important factor in maintaining an accurate response in a simple replacement accuracy task.

Stelmach and Bassin (1971) used a handle rotating task with the interpolated task being five rehearsal trials without the use of a physical stop. Increased overshooting at recall was found with the interpolated rehearsal, in comparison to recall after a rest. It was also found that the variability of the recall scores for the larger angles decreased with the repeated recalls, but the overall accuracy of the recall scores was less than recall in the control condition.

Pepper and Herman (1970) stated that the use of an interpolated task caused increased muscle tension which resulted in overshooting in the recall trial. They based their argument on the fact that the actual response trace from the criterion trial was being attended to and that this trace became augmented by the increase in muscle tension. Repeated recall of a criterion movement would presumably cause repeated overshooting, as was found by Stelmach and Bassin (1971).

CHAPTER 3

METHODS AND PROCEDURES

The variables and levels of each variable in the experiments in this research series were contingent upon the findings of the preceeding experiment(s). Since the area of motor STM has not yet been systematically investigated over a wide range of variables, the research was necessarily exploratory in nature. In the first section of this chapter the general methodology has been outlined, followed by the procedures of the individual experiments.

Apparatus

The movement apparatus used in these experiments was a joystick with an effective radius of 13 inches, designed to move in 2 dimensions within a range of 60° either side of a vertical axis. The axes of movement were the shafts of 2 potentiometers fixed at right angles to one another. The electric potential was provided by an Electro Filter D.C. Power supply, Model NFBR. The potential drop across each potentiometer caused by joystick movement was translated via a potential divider arrangement to a Honeywell 540 X-Y-Y' Recorder. The recorder was patched so that the alignment (X) and compensation (Y) components of the movement would be graphically traced across a time base at .05 centimeters per second (Figure 4). This provided an economy in the inter-trial time intervals that was unavailable with conventional X-Y plots. The subject(S), while sitting, was able to move the joystick in all directions in the horizontal plane (Figure 1). The information load was then varied by requiring the S to recall a certain number of locations within this movement range.

To initiate the input phase of each trial an EICO Model 377 Auditory Tone Generator connected to a Bogen "Challenger" Model CHB20A Amplifier was activated. The S was provided with a set of Telex Model St-20 Stereo Headphones with which he heard the tone. One-way communication between the S and the experimenter (E) was made by using an Electrovoice Model 644 Microphone, the headphones and amplifier-speaker circuits. The S remained alone in the experimental room while the E viewed the S through a one-way mirror and monitored the data from outside of the experimental room (Figure 3).

General Procedure

Each S was individually tested for each of the experiments and received verbal instructions prior to the testing. Each S remained seated in a comfortable chair

FIGURE 1 VIEW OF SUBJECT AND JOYSTICK APPARATUS

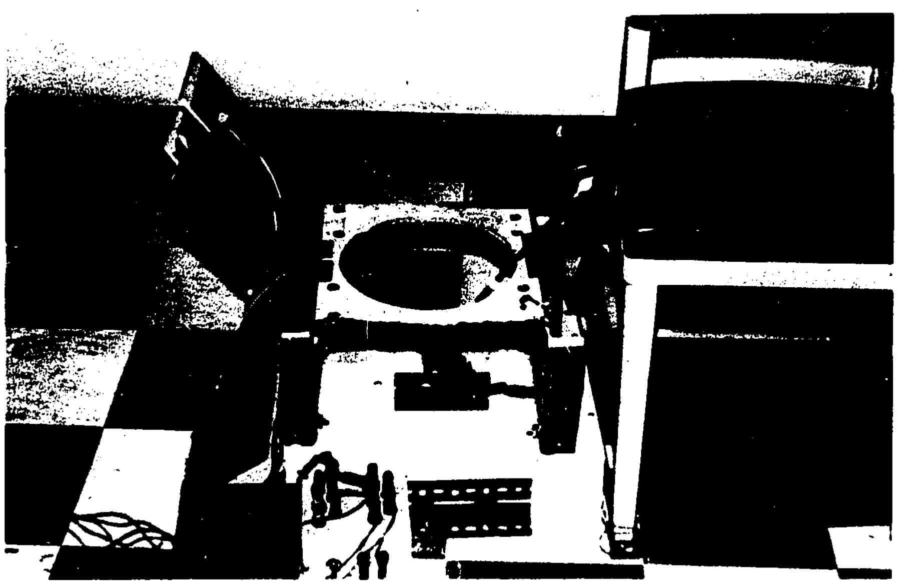
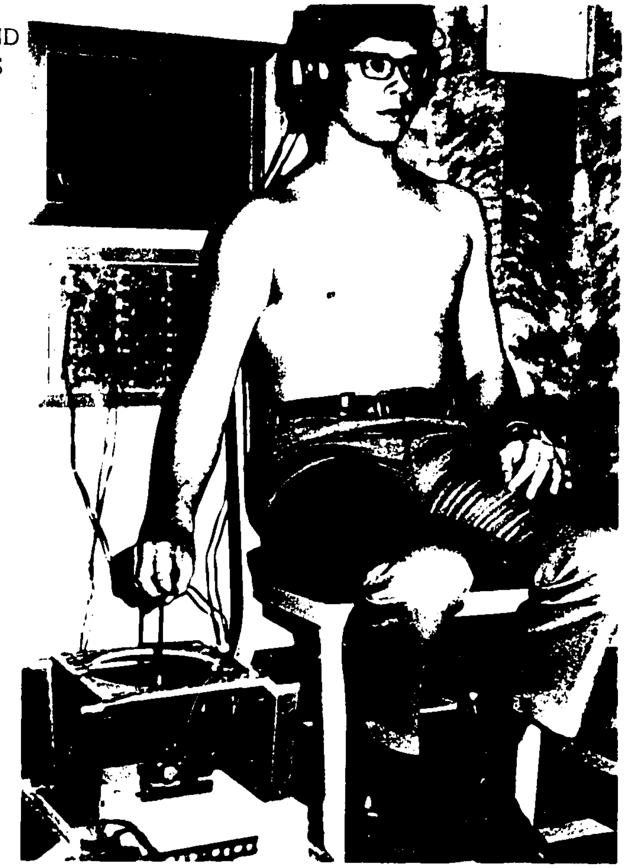


FIGURE 2 VIEW OF JOYSTICK APPARATUS WITH TEMPLATE

FIGURE 1 VIEW OF SUBJECT AND JOYSTICK APPARATUS



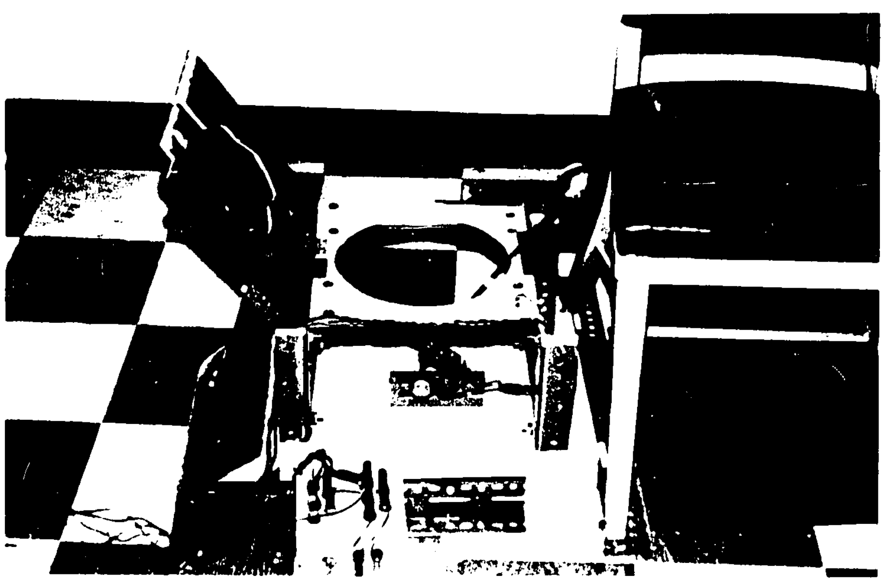


FIGURE 2 VIEW OF JOYSTICK APPARATUS WITH TEMPLATE

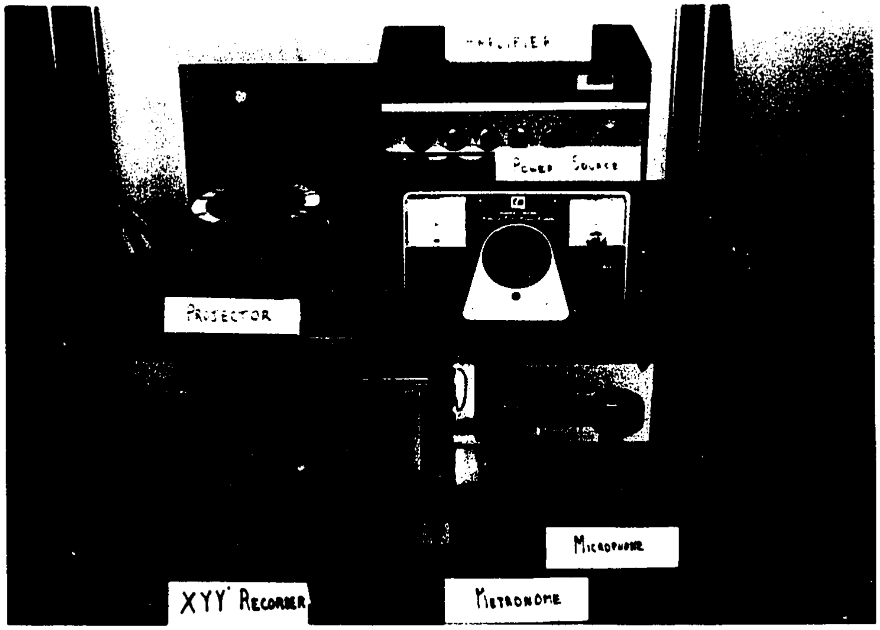


FIGURE 3 EXPERIMENTER'S VIEW OF APPARATUS

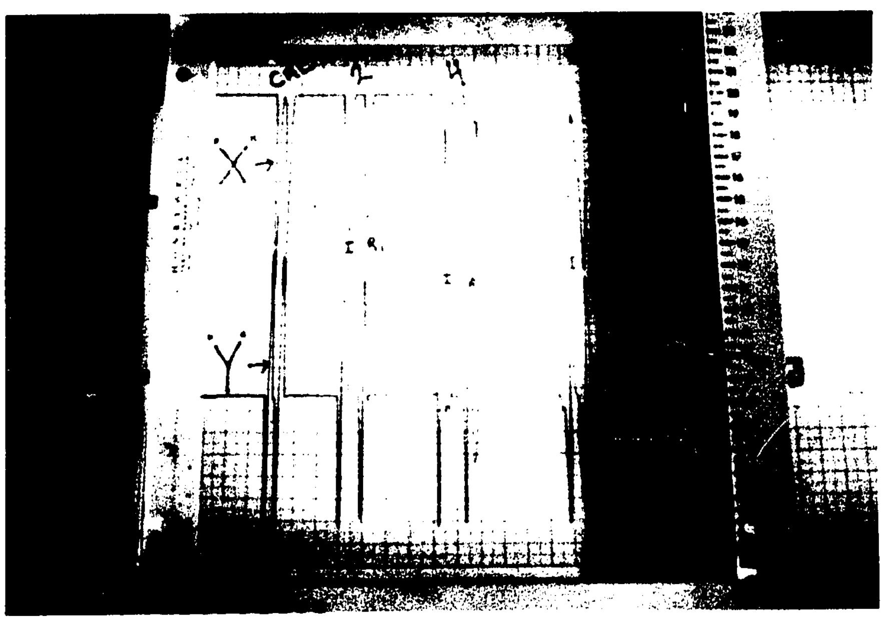


FIGURE 4 VIEW OF X-Y-Y' RECORDINGS ALONG TIME BASE FOR CALIBRATION AND THREE INPUT AND RECALL TRIALS

FIGURE 3 EXPERIMENTER'S VIEW OF APPARATUS

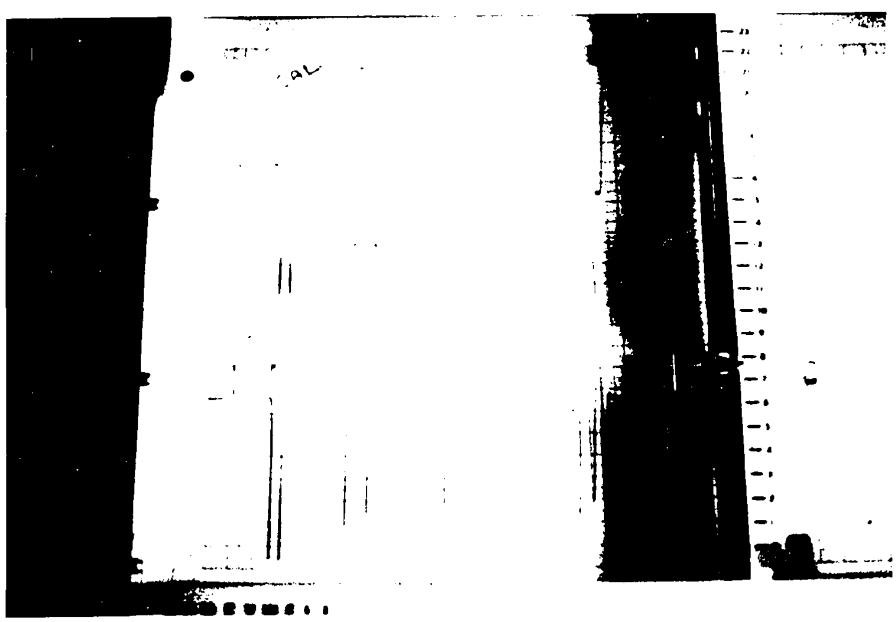


FIGURE 4 VIEW OF X-Y-Y' RECORDINGS ALONG TIME BASE
FOR CALIBRATION AND THREE INPUT AND RECALL TRIALS

throughout the entire experiment. The S was instructed to remove his shirt to prevent excessive use of tactile cues. The apparatus was situated to the S's right in such a way that he could move the joystick freely within its entire range. The S was instructed prior to each session as to the particular nature of that experiment.

The following events constituted a single trial. The S was told the nature of that particular trial. Upon hearing the tone the S held the joystick and began moving it in a series of linear movements at 1 second intervals to the beat of a mechanical metronome, changing direction after each movement for the required number of movements. Following completion of this input or criterion phase, the S sat still for the required time interval with his hand on the joystick in the null position until another tone sounded. The S, upon hearing the tone, attempted to recall and reproduce the movements of the input trial. The joystick was then returned to the null position. In all experiments the Ss were instructed to continue moving the joystick the required number of movements in the event that they forgot portions of the movement sequence.

The order of trial presentation was independently determined by sampling without replacement from Fisher and Yates (1948) random number tables.

Subjects

Twelve male physical education undergraduate and graduate students, ages 19 to 26, were chosen from the University of Alberta population. The selection was made upon the students' availability and freedom from any apparent physical handicaps.

Dependent Variables

Measurements of alignment and compensation accuracy were derived from the output on the X-Y-Y' recorder. Statistical analyses between these 2 planes have failed to reject the null hypothesis (Wilberg and Sharp, 1970; Sharp, 1971). The results of Experiment I would be analysed using both movement components and if no interaction between movement load and movement axis occurred, the rest of the experiments would be conducted using recordings in a single axis on 1 channel of the recorder.

The measurement of motor performance proceeded by using mean absolute or unsigned measures of error (AE), measures of constant or signed error (CE), as well as the mean variability about CE, or variable error (VE). The raw error scores were divided by the number of movements performed to arrive at the error per movement for each dependent variable. The use of CE and VE could be considered dependent variables reflecting positive performance, rather than AE which reflected negative performance or what the S failed to do. The interrelationship among these 3 types of errors has been outlined by Laabs (1971).

Experimental Design

The experimental design was a treatment by subjects, factorial design with repeated measures and 5 replications for each S. The levels of the main effects were deliberately selected by the E, and these were considered fixed factors. The effects of replications and subjects were considered random effects and for this reason a mixed model was assumed.

Experiment I: Generally, the research vehicle used in motor STM has been a simple replacement accuracy task. Consequently, the memory load, or number of items to be remembered, was very low in comparison to the memory span studies in verbal STM cited by Postman (1964). Only 2 studies in the motor domain have loaded the K STM system by using 2-dimensional joystick movement task (Wilberg and Sharp, 1970; Sharp, 1971). The kinesthetic load* was increased threefold, yet the variability about the absolute mean for high loading did not differ from the lower information loadings, indicating that the Ss were still working

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*The concept of information load, in this context, referred to the number of movements that the S had to remember. The measurement of information has been outlined by Miller (1956) and Attneave (1959).

within their memory span.

The purpose of this experiment was to load the K STM system to determine how much information could be held for immediate recall, as well as recall after an unfilled 20 second interval. The use of an interval of 20 seconds was arbitrary and was merely to investigate systematic effects between loading and delay intervals. A subsidiary problem would be the determination of whether the dependent variables taken in the mid-frontal and medial planes (alignment and compensation) interacted with movement load.

The experimental design used was a 5 x 2 treatment by subjects repeated measures design with 5 replications on all factors. Information load was the first factor with 5 levels of 2, 4, 8, 10 and 12 movements. Time delay was the second factor, with 2 levels of immediate recall and recall after a 20 second rest. Twelve movements were chosen because it was believed that this load could not be remembered. Miller (1956) determined that the probability of maintaining 9 to 10 errorless categories in memory across any dimension was unlikely. The 20 second delay period was chosen as a representative delay often found in the literature.

Experiment II; The main question of importance in this investigation was the determination of the type of information the S was using in K STM tasks. The procedure in Experiment I, which allowed the S to move of his own accord, could conceivably allow him to attend to a central representation of the movement, rather than afferent information from the moving limbs. Consequently, the main concern in this section of the experiment was the evaluation of a S's ability to reproduce movements (immediately and after a delay) that were in fact random and not "preprogrammed" by the S.

The experimental design was a 3 x 2 treatment by subjects, repeated measures design with 5 replications on all factors. Information load was the first factor with 3 levels of 2, 4, and 8 movements and the second factor was time delay with 2 levels of immediate recall and recall after a 20 second rest. On all trials the input movements were performed according to the visual stimulus given by the E, as described below.

The first factor of information load was selected at 3 levels of 2, 4 and 8 movements as a result of findings in Experiment I. The second factor of recall delay was chosen at 2 levels of immediate recall and recall after a 20 second rest. The 2 levels of delay were again chosen for diagnostic purposes only and the time periods had no specific theoretical relevance.

The same general experimental procedure was followed except that the S no longer moved "randomly" on his own, but moved according to visual stimuli presented by the E. Four identical sets of 20 2" x 2" black and white photographic slides were constructed, showing a circular field with a single notch in the perimeter which corresponded to the area of movement of the joystick apparatus and the "null" position, respectively. Within different areas of the field, on each of the 20 slides, was a small black dot. The Ss were instructed to move the joystick to the corresponding area in the circular movement field of the apparatus. The E presented a different slide each second for a period of 1 second on the wall in front of the S by means of a Kodak Carousel 800 Projector. The 80 slides were so arranged that the dot changed positions in a random manner about the whole area of the circular visual field. Prior to the criterion trial the S was told how many slides he was to receive. After the required number of slides had been presented the projector was turned off, the S returned the joystick to the null position and awaited the tone to recall. When the tone sounded the S attempted to recall as best he could the movements he had made on the criterion trial.

Experiment III: The question of interest in this investigation was to evaluate the quality of movement information gained by using a physical stop to terminate criterion movements, rather than allowing the S to terminate the movement willfully. If, in motor memory tasks, the S used peripheral information, the use of a physical stop or a self-controlled stop on the input trial would provide the same amount of movement information and no differences in recall should occur. But if central monitoring of information was important, self-terminated criterion movements would be best recalled.

The experimental design used was a 3 x 2 treatment by subjects repeated measures design with 5 replications on all factors. The first factor was information load with 3 levels of 2, 4 and 8 movements, and the second factor was the type of end point with 2 levels of self-terminated (free) end point and physical (templated) end point.

The free condition was identical to the non-delay condition for up to 8 movements in Experiment I. Before starting the templated condition, the S secured an irregularly shaped hinged template over the movement area of the apparatus. The S followed the general procedure described earlier, except that each change in direction could be made only after reaching a padded irregular edge of the template. Having completed the required number of movements and having returned the joystick to the null position, the S touched a button on the apparatus that released the counter-balanced template, allowing it to swing away (Figure 2). Once the template was cleared the E sounded the tone and the S attempted to reproduce the movement without the aid of the template. The experiment proceeded so that the templated trial was alternated with a free trial.

Experiments IV and V: The question of experimental interest in these investigations was the determination of the S's response consistency when the method of movement input was varied. For example, self-controlled movements and experimenter-controlled movements may require the S to attend to different sources of information, i.e., central versus peripheral, which may differ in fidelity or meaningfulness. The response consistency under these conditions was to be observed.

The experimental designs used were 3 x 2 x 2 treatment by subjects, repeated measures designs, with 5 replications on all factors. Information load was the first factor with 3 levels of 2, 4 and 8 movements; method of movement input was the second factor with 2 levels of self-determined movement (free) and experimenter-determined movement (slides) and number of recall trials was the third factor with 2 and 4 recall trials for Experiment IV and Experiment V, respectively.

The procedures for the experiments were identical to those described above in Experiments I and II, except that in Experiment IV, after two, 10 second rest intervals, the S recalled the criterion trial twice. In Experiment V, 4 recalls were made after four 5 second intervals.

Apparatus Calibration

For a period of 1 week prior to the experimentation, standard calibration recordings were taken from the X and Y axes at four 15 minute periods and compared. During the experimentation, but prior to the first trial, the S made a standard calibration movement around the edge of the movement area and results of these calibrations were analysed (Figure 4). No significant differences occurred throughout the experiment between subjects or between experiments (Appendix F, Tables 45 and 46).

Statistical Analysis

The data for each analysis were analysed using 3 analyses of variance for absolute error, constant error and variable error. Newman-Keuls Test was used as a test between means for the significant main effects. Analysis of variance techniques were used to analyse any simple main effects for significant interactions. The use of 5 replications per cell allowed the S's variability about his constant error to be calculated. By treating replications as a factor, any fatigue or learning effects throughout the course of the experiment could be determined. Paull's (1950) pooling criterion was used to determine the best estimate of experimental error to test the main effects.

A conservative level of rejection was chosen (alpha = .01) to decrease the probability of making a Type I error on this exploratory study. The use of a repeated measures design provided for each S to act as his own control, thus decreasing the within treatment variance. Since this procedure also increased the probability of treatment effects being correlated, the Greenhouse and Geisser (1959) conservative degrees of freedom were used in the preliminary analyses to evaluate heterogeneity of covariance.

CHAPTER 4

ANALYSIS

In repeated measures designs, the conventional F ratios for tests involving the repeated measures will have the F distribution only if all pairs of repeated measures have equal covariances (Wilson, 1971). In this series of investigations preliminary analyses using the Greenhouse and Geisser (1959) conservative degrees of freedom were used to test the validity of the covariance assumption. Based upon the results of these analyses, the power of the primary analyses were determined. The conclusions were drawn upon the primary analyses which followed, using conventional degrees of freedom.

Experiment I

<u>Hypotheses</u>

Three hypotheses were formulated in accordance with the related literature:

H_1: Errors for 2 movements $<$ Errors for 4 movements $<$ Errors for 8 movements $<$ Errors for 10 movements $<$ Errors for 12 movements for absolute, constant and variable error scores,

H_2: Errors for immediate recall = Errors for recall after 20 seconds for absolute, constant and variable error scores.

H_3: Errors for alignment = Errors for compensation for absolute, constant and variable error scores.

In the first hypothesis, recall performance was considered to be inversely related to information load, or the number of movements to be remembered. Anderson (1960) demonstrated that this hypothesis was not rejected in verbal STM, while Wilberg and Sharp (1970) and Sharp (1971) substantiated this hypothesis using this same movement apparatus and sub-memory span loads. Specific hypotheses regarding the effect of supra-memory span loads were not stated because the type of information used by the Ss to respond was not clearly known.

The second hypothesis was formed to demonstrate that recall performance would be the same for immediate recall and recall after an unfilled interval of 20 seconds. Sharp (1971) found no performance decrement after a 15 second rest using the same apparatus. This hypothesis was contrary to that proposed by Pepper and Herman (1970) who stated that the memory trace would decay spontaneously unless overtly rehearsed.

With the third hypothesis, it was intended to demonstrate that alignment and compensation scores would not differ in recall accuracy. Siddal, Holding and Draper (1957) found that the Ss were equally accurate in both the mid-frontal and medial planes. Sharp (1971) confirmed these results at the 0.05 level of confidence, but not at the 0.01 level of confidence.

Results

Preliminary Analysis: Three 3-way analyses of variance, using the Greenhouse and Geisser (1959) conservative degrees of freedom, were carried out on the absolute, constant and variable error scores as the dependent variables (Appendix A, Tables 16, 17 and 18 respectively). The null hypothesis was not rejected using the conservative tests for any independent variable in the 3 analyses.

Primary Analysis: Two 5-way analyses of variance and a 4-way analysis of variance, using conventional degrees of freedom, were carried out with the absolute, constant and variable error scores (Tables 1, 2 and 3 respectively). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test these main effects. In all 3 analyses, the main effect of information load or number of movements to be remembered and the effect of subjects were significant beyond the 0.01 level of confidence. The main effect of recall delay was not significant at the 0.01 level of confidence for absolute, constant or variable error. The main effects of movement axis (compensation and alignment) were found significant at the 0.05 level for absolute error, significant at the 0.01 level for constant error and not significant at either level for variable error. The effect of replications was also calculated and for all dependent variables was not significant at the 0.01 level. There was also a movement by subjects interaction effect for absolute error, significant at the 0.01 level. The means for the 3 main effects, based on 60 scores, were reported in Appendix A, Table 19. The graphs of the main effects for absolute, constant and variable error are illustrated in Figures 5, 6 and 7 respectively.

Newman-Keuls Test was applied to the means of the levels of information load for absolute, constant and variable error scores, respectively (Appendix A, Table 20). For absolute error scores 2 movements differed from 8, 10 and 12 movements and 4 movements differed from 10 and 12 movements at the 0.01 level of confidence. Using constant error scores, 2 and 4 movements differed from 8, 10 and 12 movements and 8 movements differed from 10 and 12 movements at the 0.01 level of confidence. With variable error scores, 2 movements differed from 4, 8, 10 and 12 movements and 8 movements differed from 10 and 12 movements at the 0.01 level of confidence.

TABLE 1

FIVE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	452923	4	113230.7	112.40**
Delay (D)	2092	1	2091.6	2.07
M x D	5425	4	1356.6	1.34
Axis (A)	6177	1	6177.7	6.10*
M x A	6309	4	1577.3	1.56
D x A	0	1	0.0	.00
M x D x A	2219	4	554.7	.55
Replications (R)	3222	4	805.4	.80
D x R	2652	4	662.9	.62
A x R	3567	4	891.8	.89
D x A x R	2918	4	729.5	.73
Subjects (S)	326940	11	29721.8	29.52**
M x S	223768	44	5085.6	5.05**
Pooled Error	1116692	1109	1006.9	

TABLE 2

FIVE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	32691	4	8172.8	62.87**
Delay (D)	62	1	62.0	.48
M x D	500	4	125.0	.96
Axis (A)	1589	1	1589.0	12.20**
M x A	259	4	64.6	.50
D x A	44	1	44.0	.34
M x D x A	457	4	114.2	.88
Replications (R)	753	4	188.3	1.45
D x R	596	4	149.0	1.15
A x R	57	4	14.4	.11
D x A x R	330	4	82.5	.63
Subjects	16224	11	1474.9	11.34**
Pooled Error	150172	1153	130.2	

** significant at the 0.01 level
* significant at the 0.05 level

TABLE 3

FOUR WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	130	4	32.6	8.69**
Delay (D)	1	1	1.0	.27
M x D	11	4	2.8	.75
Axis (A)	5	1	5.0	1.33
M x A	23	4	5.8	1.55
D x A	8	1	8.0	2.13
M x D x A	16	4	4.0	1.07
Subjects	112	11	10.2	2.70**
Pooled Error	783	209	3.7	

** significant at the 0.01 level

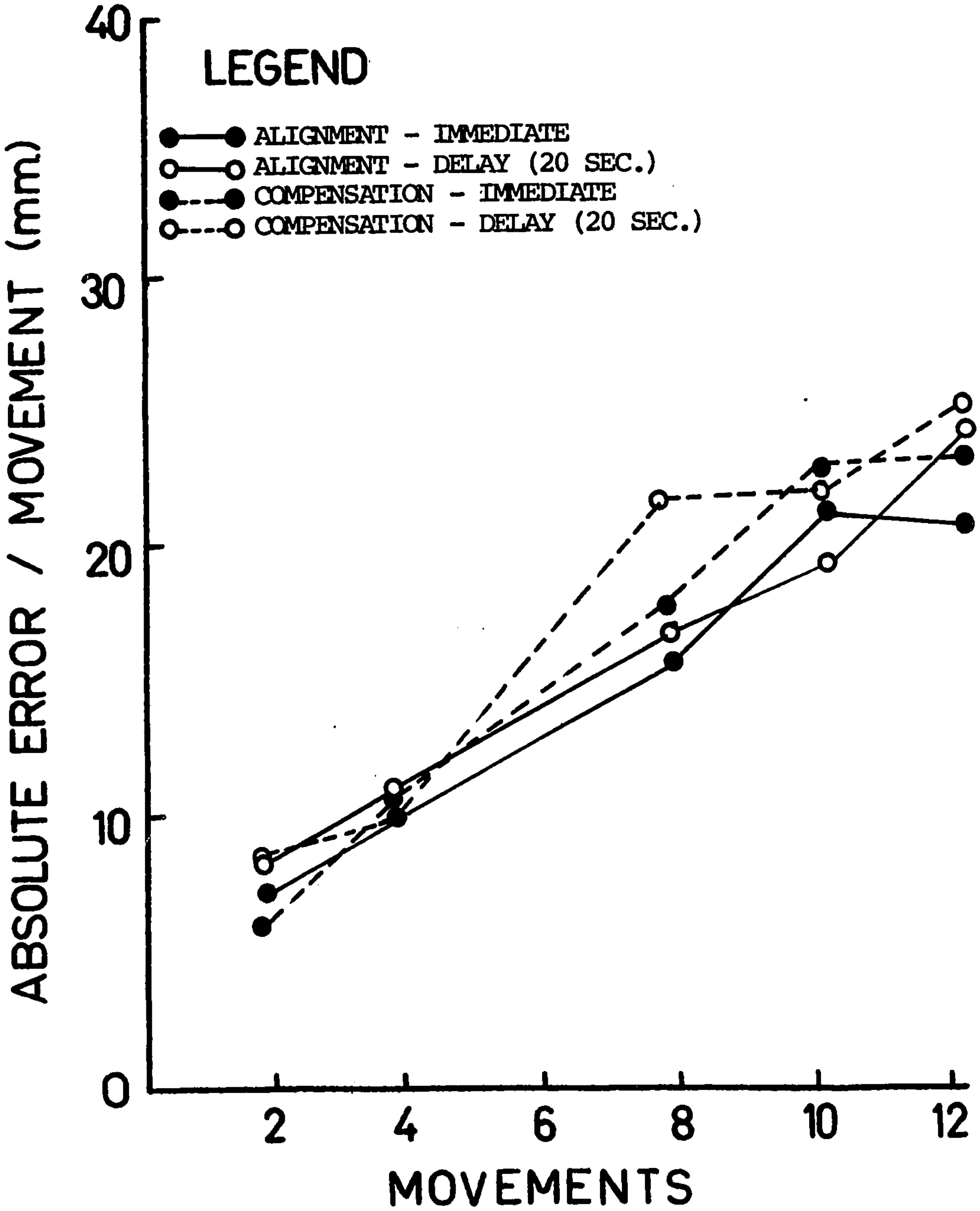

FIGURE 5 THE MEAN ABSOLUTE ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAY FOR ALIGNMENT AND COMPENSATION

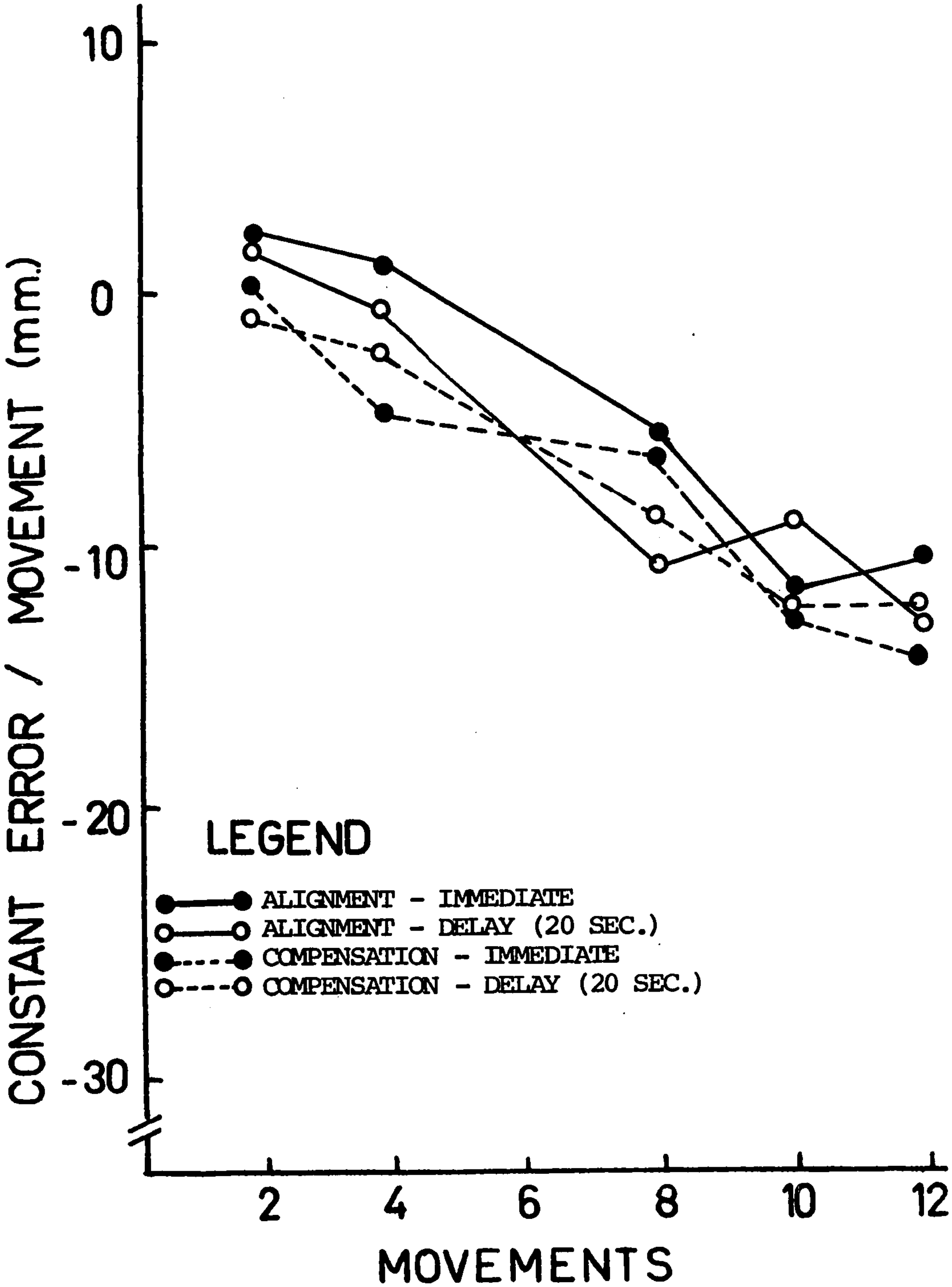

FIGURE 6 THE MEAN CONSTANT ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAY FOR ALIGNMENT AND COMPENSATION

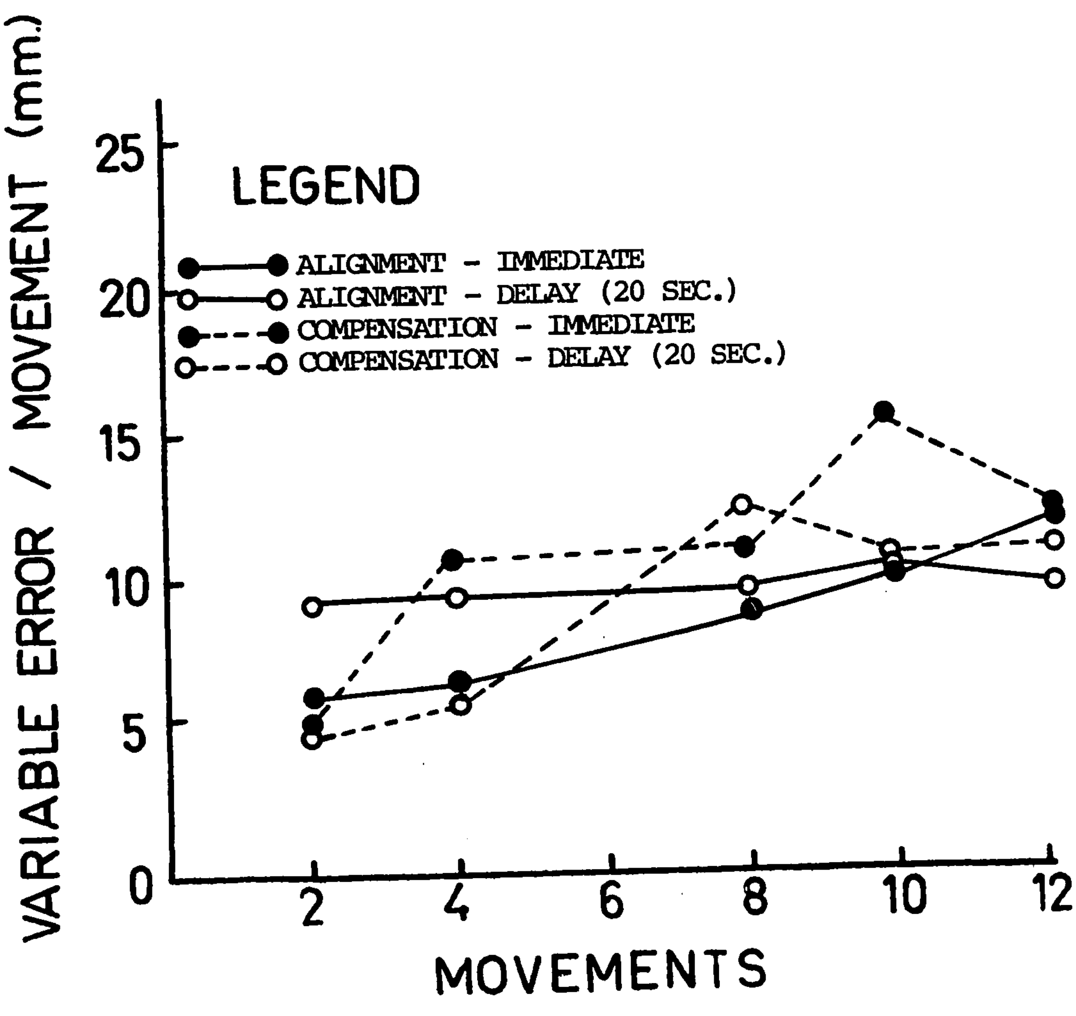

FIGURE 7 THE MEAN VARIABLE ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAY FOR ALIGNMENT AND COMPENSATION

Discussion

Preliminary Analysis: The failure to reject any null hypothesis using the conservative test of Greenhouse and Geisser (1959) indicated that there was a high probability of violation of the homogeneity of covariance assumption for the primary analysis of variance. Reasons why this violation occurred were outlined below in the discussion on response strategies. Based on this analysis, the primary analysis was conducted in an exploratory manner to direct further investigation. Consequently, conclusions could not legitimately be drawn.

Information Load: The results obtained for the main effect of information load, or the number of movements to be recalled, were partially in accord with the first hypothesis that recall accuracy was inversely proportional to memory load. Wilberg and Sharp (1970) and Sharp (1971) found consistent findings using absolute error only, with sub-memory span loads on the same apparatus.

The use of constant and variable error scores as dependent variables, in addition to the absolute error scores, provided information that was not previously investigated using this type of task. There was a general trend displayed, with one exception, that forgetting had not occurred between 2 and 4 movements, or between 10 and

12 movements. It seemed that 2 or 4 movements, if measured by absolute or constant error scores, could be remembered equally well by the Ss; but differences did occur if the consistency of the constant error responses was calculated by variable error scores. The fact that differences did not occur for absolute and constant error scores for 2 and 4 movements when the information load was doubled, indicated to this writer that the Ss might not have been attending to the afferent information, but rather to more stable efferent information.

The consistent finding that no differences occurred between 10 and 12 movements for all dependent variables might be explained by one of 2 hypotheses. First, the Ss may have decided a priori that they could not recall 10 and 12 movements and therefore adopted a response mode whereby they traced a series of well-learned patterns (e.g., squares and triangles) which were reproducable. Further, it was also possible that the Ss did not consciously adopt such a strategy, but attempted to move "randomly" as instructed for the 10 and 12 movements. Ordinarily, this information load, as stated by Miller (1956), would be well above the number of errorless categories that the Ss could remember and absolute error differences should have increased in this range. However, in responding, the Ss might have selected a "random" sub-routine that was, in fact, well-routinized and was similar in nature to the input trial. The reports of the Ss indicated that they may have operated in both of these modes, although the latter "strategy" was believed by them to be ineffective.

The possibility that 2 or more strategies were used differentially by the Ss during the experiment for high and low information loads was supported by the significant movement by subjects interaction. Evidence of multiple strategies was also given by the non-significance of the analysis of variance using Greenhouse and Geisser (1959) conservative degrees of freedom. This procedure was sensitive to deviations from homogeneity of covariance, especially if these deviations were polarized to 2 strategies (Wilson, 1971). To help avoid future covariance deviations which were contrary to analysis of variance assumptions, further experimentation was confined to information loads of 2, 4 and 8 movements. This number of items was demonstrated by Miller (1956) to be close to the normal memory span for most dimensions and might therefore preclude the use of differential strategies by the Ss. Further evidence was given to this point by Sharp (1971) who failed to find treatment by subjects interactions using this same load.

Information Loss: The results obtained for the main effect of recall delay were in agreement with the second hypothesis. Sharp's (1971) finding that delay effects did not occur over an unfilled interval for sub-span information loads were confirmed in this investigation. This finding was contrary to the spontaneous trace decay concept that Pepper and Herman (1970) proposed. This writer believed that the Ss, with this task, used a central movement pattern that was relatively impervious to decay, rather than attending to a more unstable form of peripheral information available from the movement.

Axis of Movement: The results obtained for the main effect of axis of movement for absolute and variable error scores supported the third hypothesis of no significant axis effect. Absolute error scores did differ, however, at the 0.05 level of confidence. Measures of constant error scores, which are more sensitive to positive performance changes (Laabs, 1971), rejected the null hypothesis at the 0.01 level of confidence. Mean constant error scores for both movement components (Table 2) were more accurate for alignment than for compensation scores. Similar results were found by Sharp (1971) at the 0.05 level of confidence. These differences might have been an artifact of the equipment's being at the side of the Ss. Alignment movement components would perhaps be more accurate since they were limited by the Ss arm length (i.e., a "ceiling effect"), while there was no such constraint in the compensation component. Because of the fact that no treatment by axis interactions were significant, further analysis was limited to the compensation components of the joystick movements.

Replications: The replications effect was not significant at the 0.01 level of confidence. This indicated that the Ss did not demonstrate any significant fatigue or learning effects throughout the course of the experiment. Furthermore, a lack of significant replication's effect was considered essential to the continued use of the Ss throughout successive experiments (Tables 1, 2 and 3).

Subjects: The Ss were significantly different from each other at the 0.01 level of confidence, indicating that large individual differences existed.

Experiment II

Hypotheses

Two hypotheses were formulated on the basis of the related literature:

H_1: Errors for 2 movements $<$ Errors for 4 movements $<$ Errors for 8 movements for absolute constant and variable error scores.

H_2: Errors for immediate recall = Errors for recall after 20 seconds of rest for absolute, constant and variable error scores.

In the first hypothesis, it was held that recall performance would deteriorate as the information load increased. The justification for this hypothesis was demonstrated by Wilberg and Sharp (1970) and Sharp (1971). However, in that the Ss could not as readily use pre-planned motor output when the input was experimenter-controlled, it was believed that absolute performance would be more "errorful" than performance at identical information loads in Experiment I. This comparison would not be tested statistically until Experiments IV and V.

The second hypothesis was formed to demonstrate that no differences would occur between the main effect of immediate recall and recall after un unfilled interval of 20 seconds. This hypothesis was stated in the null form because the E could not be certain if the Ss were using more stable response strategies, rather than attending and responding according to the peripheral motor input. It was, however, believed that the Ss were forced to attend more closely to peripheral information with this method of input than with the less rigidly controlled method of input in Experiment I.

Results

Preliminary Analysis: Three 2-way analyses of variance were carried out on the absolute, constant and variable error scores using the Greenhouse and Geisser (1959) conservative degrees of freedom (Appendix B, Tables 21, 22 and 23 respectively). The null hypothesis was not rejected for any of the dependent variables at the 0.01 level of confidence. However, significance at the 0.10 level of confidence was reached in the absolute and variable error scores analyses, and was approached by the constant error score analysis.

Primary Analysis: Two 4-way analyses of variance and a 3-way analysis of variance, using conventional degrees of freedom, were performed on the absolute, constant and variable error scores, respectively (Tables 4, 5 and 6). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test these main effects. In all 3 analyses, the main effect of information load, or number of movements to be remembered, and the effect of subjects were significant past the 0.01 level of confidence. The main effect of recall delay was not significant at the 0.01 level for any dependent variables. The interaction for delay by replications was found to be significant for absolute error and constant error at the 0.05 and 0.01 levels of confidence, respectively. The interaction of movements by replications for variable error was also significant at the 0.05 level of confidence. The replications effect was not significant at the 0.01 level of confidence. Treatment by subjects interaction effects did not occur with any of the dependent variables. The graphs of the main fixed effects, based on 60 scores, for absolute, constant and variable error scores were plotted in

TABLE 4

FOUR WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	23140	2	11570.4	81.25**
Delay (D)	57	1	57.0	.40
M x D	17	2	8.5	.06
Replications (R)	418	4	104.7	.74
D x R	1770	4	442.6	3.11*
Subjects	7287	11	662.5	4.65**
Pooled Error	47771	335	142.4	

TABLE 5

FOUR WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	2274	2	1137.0	49.01**
Delay (D)	8	1	8.0	.35
M x D	10	2	5.0	.22
Replications (R)	74	4	18.5	.80
M x R	400	8	50.0	7.16*
D x R	348	4	87.0	3.75**
Subjects	564	11	51.3	2.22**
Pooled Error	7386	319	23.2	

** significant at the 0.01 level
* significant at the 0.05 level

TABLE 6

THREE WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	13.1	2	6.5	16.25**
Delay (D)	.5	1	.5	1.25
M x D	.7	2	.4	1.00
Subjects	14.1	11	1.3	3.25**
Pooled Error	22.1	55	.4	

** significant at the 0.01 level

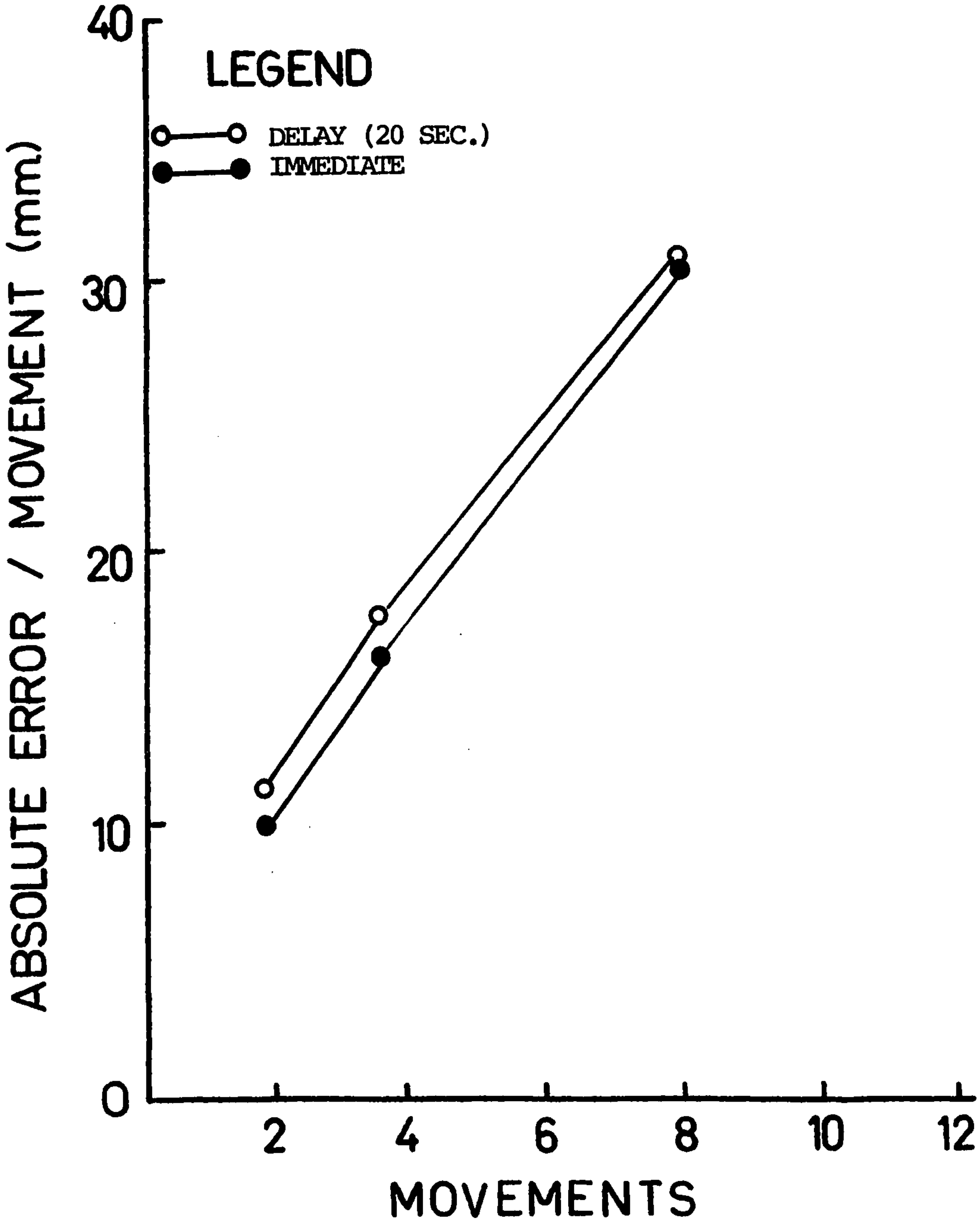

FIGURE 8 THE MEAN ABSOLUTE ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAYS WITH EXPERIMENTER-CONTROLLED MOVEMENT INPUT

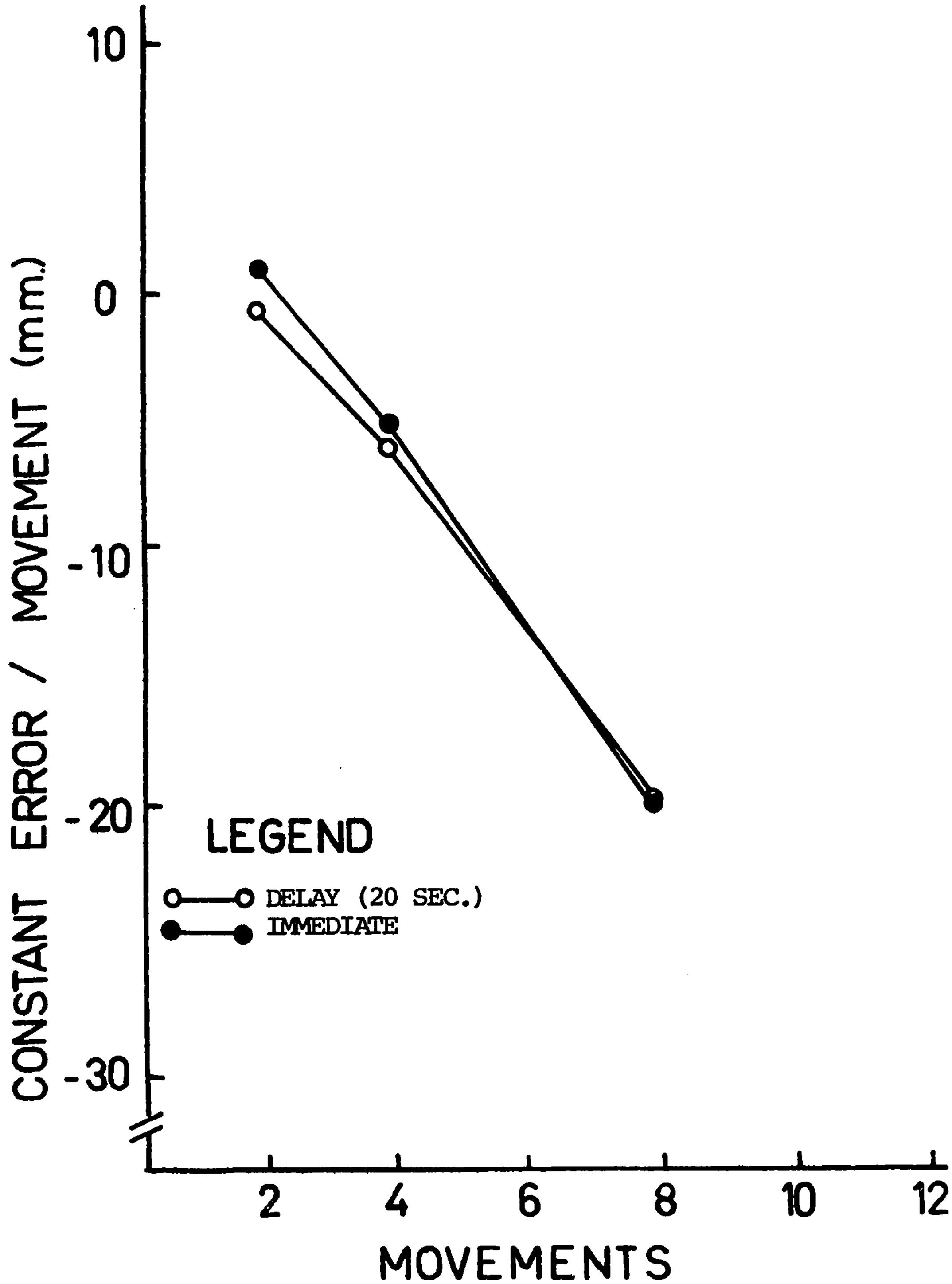

FIGURE 9 THE MEAN CONSTANT ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAYS WITH EXPERIMENTER-CONTROLLED MOVEMENT INPUT

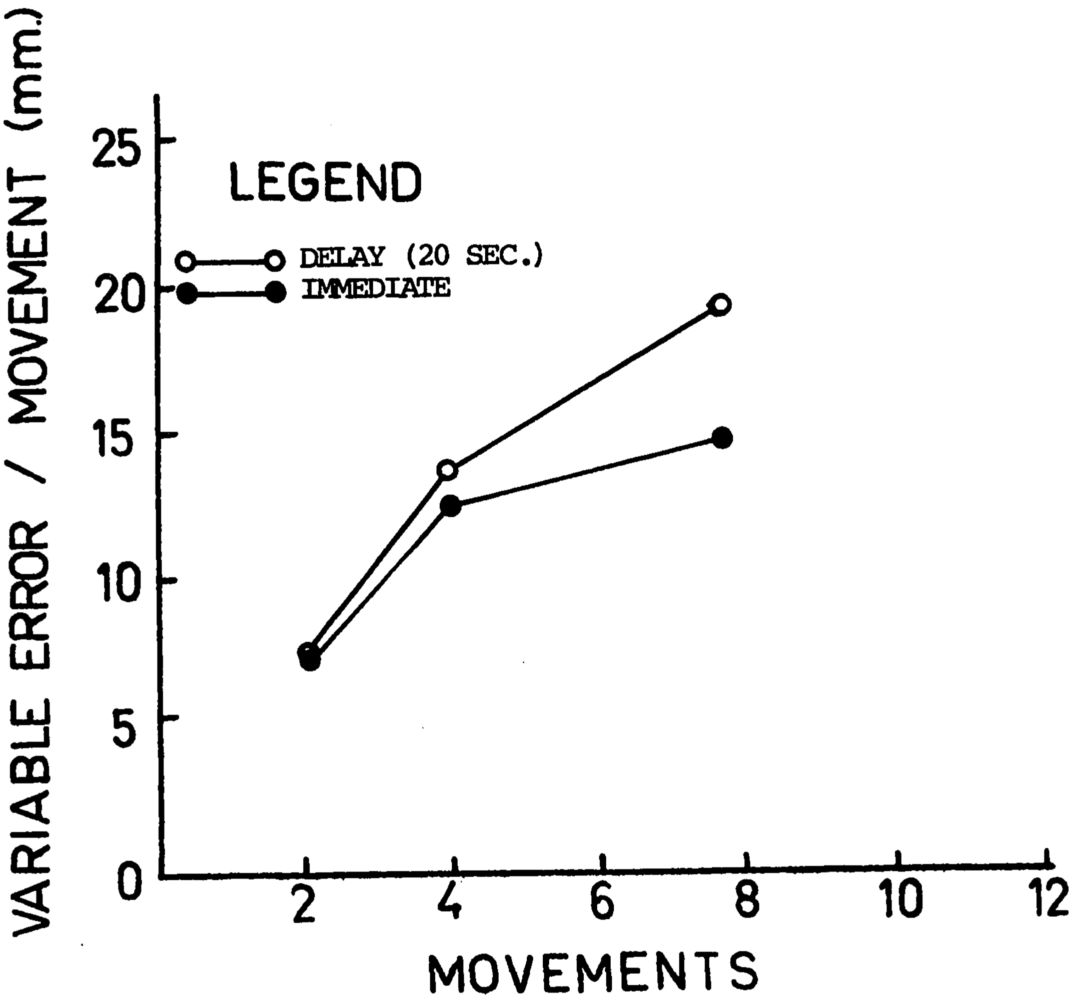

FIGURE 10 THE MEAN VARIABLE ERROR FOR THE NUMBER OF MOVEMENTS AND RECALL DELAYS WITH EXPERIMENTER-CONTROLLED MOVEMENT INPUT

Figures 8, 9 and 10, respectively. The means of the main fixed effects were reported in Appendix B, Table 24.

Newman-Keuls Test was applied to the means of the levels of the information load for absolute, constant and variable error scores (Appendix B, Table 25). For each set of dependent variables all means differed from all other means, exceeding the 0.01 level of confidence.

Discussion

Preliminary Analysis: The use of the Greenhouse and Geisser (1959) conservative degrees of freedom protects an E against making a Type I error in the face of maximum heterogeneity of covariance. Wilson (1971) stated that the use of the conservative degrees of freedom was unsatisfactory unless:

> ...one half of the repeated measures equals one of a pair of independent random variables and the other half equals another.

The information load of this experiment was reduced to preclude the use of multiple response strategies, as in Experiment I, which might have caused heterogeneous covariance. Also, using the conservative degrees of freedom, absolute and variable error scores for information load both reached the 0.10 level and constant error scores for information load approached the 0.10 level of confidence. It was therefore considered justifiable to assume that the corrected degrees of freedom, if adjusted for covariance deviations as outlined by Wilson (1971) would render the assumptions of analysis of variance satisfied. This would allow the conventional degrees of freedom to be used in the primary analysis.

Information Load: The results obtained for the main effect of information load for absolute, constant and variable error scores were fully in accord with the first hypothesis. The use of experimenter-controlled input tended to increase the differences between the different levels of the information load as indicated by the significant differences found between 2 and 4 movements for all dependent variables (Appendix B, Table 25). In Experiment I, differences could not be found between 2 and 4 movements for absolute and constant error scores. Sharp (1971) used a similar input technique to that of Experiment I and was not able to detect differences between 2 and 4 movements. The use of the experimenter-controlled method of input seemed to prevent the Ss from using well-routinized movement patterns at low levels of information load. If it could be assumed that the Ss attended to the movement stimuli available from peripheral sources, it was evident that he could not do so as accurately in this investigation as he could in Experiment I (Figures 5-10). This decrement might have been due to the lack of fidelity or meaningfulness of the movement produced information, as Wilberg (1969b) suggested. In the face of information that possibly could not be coded or organized, the Ss might have ignored the movement-produced stimuli altogether while responding independently, either to the given instructions or to their "ideo-motor" concept of the criterion movement (Greenwald, 1970). When a movement system is used as input as well as output, it becomes difficult to tell how much "representation of the stimulus" the S used to make the response (Posner, 1963). These ideas were tested more directly in Experiments IV and V. The lack of a movement by subjects interaction indicated that, whatever the response mode chosen by the Ss, it was at least consistent across all information loads.

Information Loss: The results obtained for the main effect of recall delay were in agreement with the second hypothesis. If a response trace susceptible to spontaneous decay was formed by peripheral input (as Pepper and Herman (1970) assumed), the experimenter-controlled input used in this investigation would tend to focus the Ss attention on this source. The lack of a recall decrement over a 20 second unfilled interval indicated that a more stable trace was being attended to; possibly from a LTM movement store. Adams' (1967) delineation between a permanent memory trace and a more fleeting environmental perceptual trace, might be appropriate here. The information provided in the joystick task provided few reliable location cues because the joystick was free-moving as well as being out of the Ss sight. Further experimentation did not include delay factors since the null hypothesis was not rejected for this factor in either Experiments I or II.

Replications and Subjects: The replications effect was again not significant at the 0.01 level of confidence. This indicated that any learning or fatigue effects experienced by the Ss during the course of the experiment were not significant. The interactions that occurred between the replications and delay for absolute and variable error were unexpected and were believed to be a result of the population sample. The subjects effect was again significant, but the lack of treatment interaction with this effect indicated that, although the Ss showed great individual differences, these differences were consistent across all treatment conditions. Reduction of the extreme information loads of Experiment I was believed to have eliminated the treatment by subjects interaction as well the extreme covariance deviations, by restricting the possible response strategies.

Experiment III

Hypotheses

Two hypotheses were formed in accordance with the related literature:

H_1: Errors for 2 movements $<$ Errors for 4 movements $<$ Errors for 8 movements for absolute, constant and variable error scores.

H_2: Errors for the free end point condition = Errors for the templated end point condition for absolute, constant and variable error scores.

In the first hypothesis recall performance decrements were considered to be an increasing function of the information load, or the number of movements to be recalled. Support for this hypothesis was gained by Wilberg and Sharp (1970) and Sharp (1971), and from Experiments I and II.

The second hypothesis was formed to demonstrate whether recall differences would occur for any dependent variables between the free end point and the templated end point for criterion trials. This hypothesis was stated in the null form because of uncertain evidence concerning this phenomenon. Posner (1967a) and Stelmach (1969, 1970), among others, have used physical stops to control the extent of the criterion movement in motor STM tasks. Wilberg (1971) has found that no differences occurred between recall conditions when the criterion trial was terminated by a physical stop, a self-terminated stop or a stop to a tone. Greater response accuracy would be predicted for the free end point condition, if the Ss actually monitored the efferent motor information rather than peripheral movement-produced stimuli.

Results

Preliminary Analysis: Three 2-way analyses of variance were carried out on the absolute, constant and variable error scores using the Greenhouse and Geisser (1959) conservative degrees of freedom (Appendix C, Tables 26, 27 and 28). The null hypothesis was not rejected for any of the dependent variables at the 0.01 level of confidence.

Primary Analysis: Two 4-way analyses of variance and a 3-way analysis of variance were computed on the absolute, constant and variable error scores, respectively (Tables 7, 8 and 9). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test these main effects. The main effect of information load, or the number of movements recalled, was significant at the 0.01 level of confidence for absolute, constant and variable error scores. The main effect of end point was significant at the 0.01 level of confidence for absolute and variable error scores. The effect of end point for constant error scores was not significant at the 0.01 level of confidence. The effect of subjects was again significant at the 0.01 level of confidence for absolute and constant error scores, but not for variable error scores. The graphs of the main fixed effects, based on 50 scores, were illustrated in Figures 11, 12 and 13, respectively. The means of the main fixed effects were reported in Appendix C, Table 29. The scores for 2 Ss were dropped from the analysis for failing to follow instructions regarding the recall trials.

Newman-Keuls Test was applied to the means of the levels of information load for absolute, constant and variable error scores (Appendix C, Table 30). For the mean absolute error scores, 2 movements differed from 8 movements and 4 movements differed from 8 movements at the 0.01 level of confidence. For the mean constant and variable error scores, all means differed at the 0.01 level of confidence.

The effect of replications was not rejected at the 0.01 level of confidence. The effect of subjects was rejected at the 0.01 level of confidence, but no treatment by subjects interactions were significant.

TABLE 7

FOUR WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	9135	2	4567.7	34.21**
End Point (E)	3234	1	3234.0	24.22**
M x E	313	2	156.6	1.17
Replications (R)	157	4	39.3	.29
E x R	370	4	92.5	.69
Subjects	5606	9	622.9	4.67**
Pooled Error	36979	277	133.5	

TABLE 8

FOUR WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	866	2	433.0	27.06**
End Point (E)	8	1	8.0	.05
M x E	79	2	39.4	2.46
Replications (R)	5	4	1.3	.08
E x R	77	4	19.3	1.21
Subjects	471	9	52.4	3.28**
Pooled Error	4420	277	16.0	

** significant at the 0.01 level

TABLE 9

THREE WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	4.9	2	2.5	5.0**
End Point (E)	2.0	1	.2	4.0*
M x E	.4	2	.2	.4
Subjects	6.4	9	.7	1.4
Pooled Error	20.4	45	.5	

** significant at the 0.01 level
 * significant at the 0.05 level

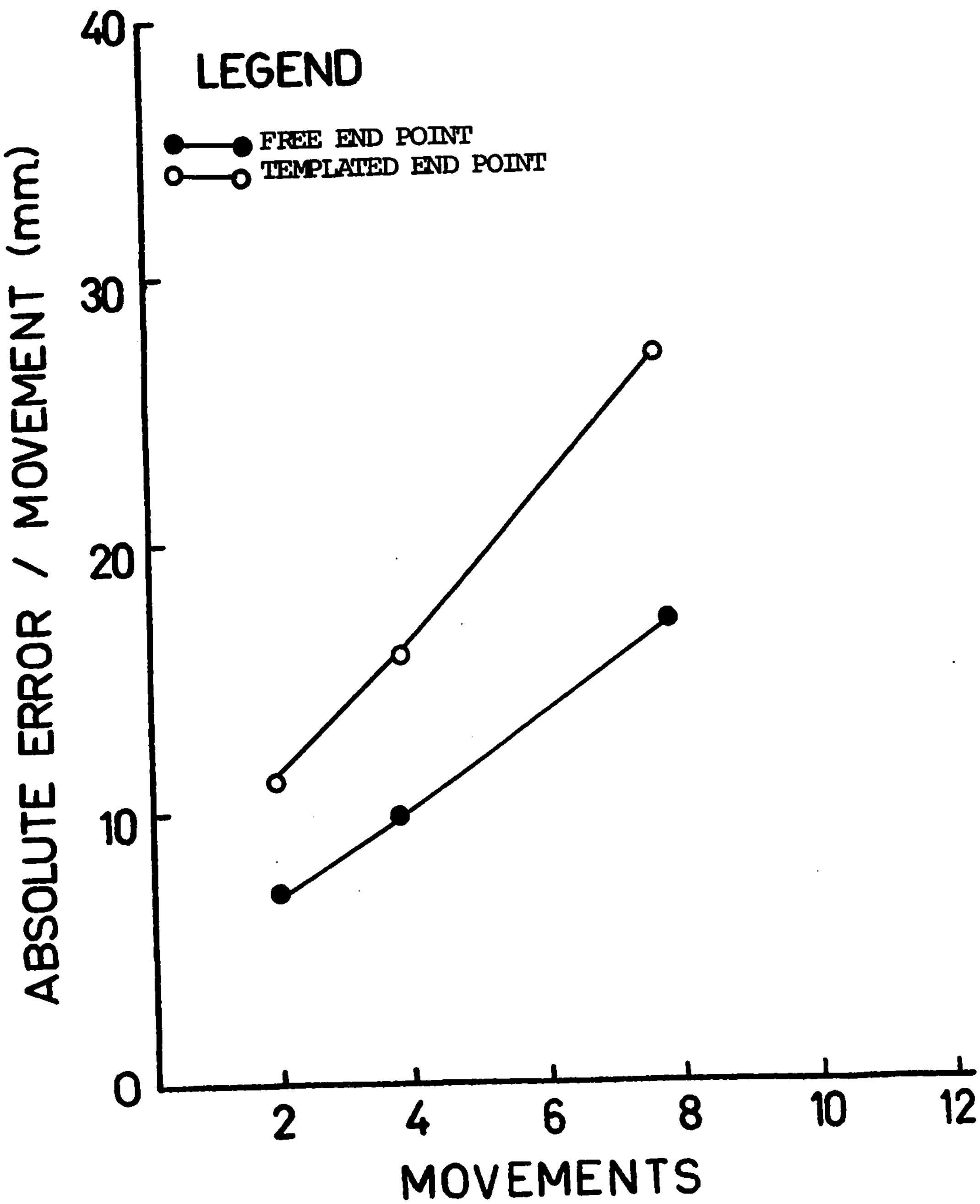

FIGURE 11 THE MEAN ABSOLUTE ERROR FOR THE NUMBER OF MOVEMENTS WITH FREE AND TEMPLATED END POINT CONTROL

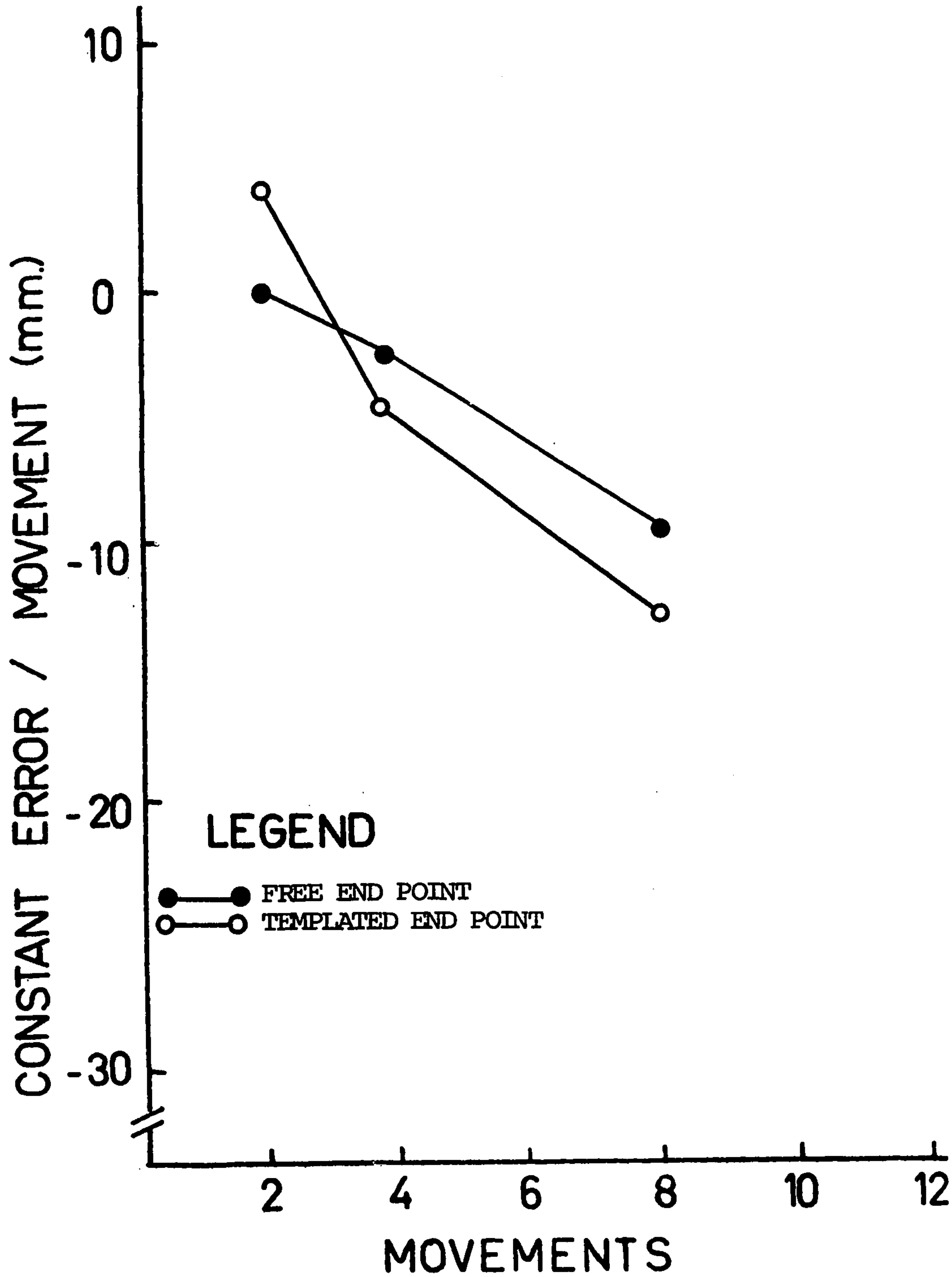

FIGURE 12 THE MEAN CONSTANT ERROR FOR THE NUMBER OF MOVEMENTS WITH FREE AND TEMPLATED END POINT CONTROL

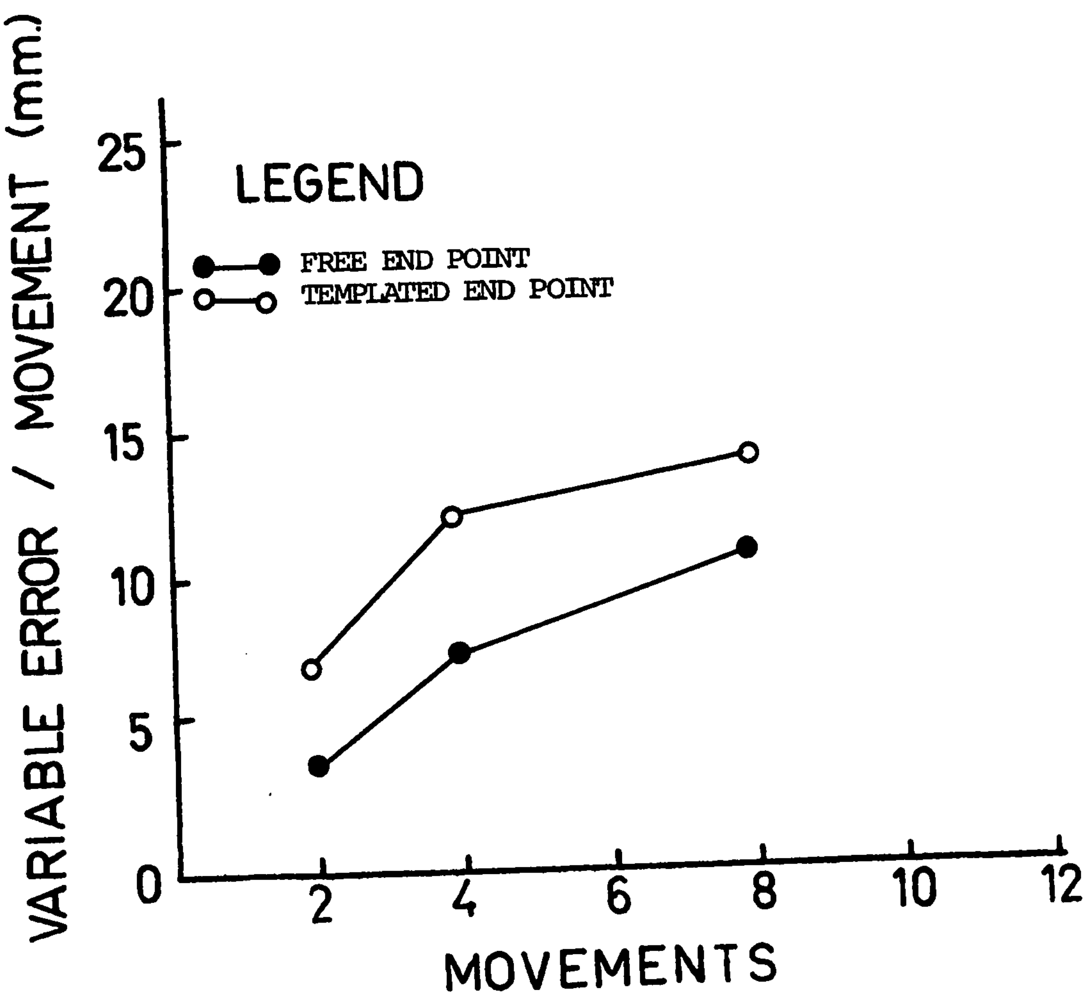

FIGURE 13 THE MEAN VARIABLE ERROR FOR THE NUMBER OF MOVEMENTS WITH FREE AND TEMPLATED END POINT CONTROL

Discussion

Preliminary Analysis: The failure to reject the null hypothesis for any dependent variable using the Greenhouse and Geisser (1959) conservative test indicated that the analysis of variance assumption of homogeneity of covariance may have been violated. A decision was made by this writer that the reported tabled values for making a Type I error for absolute and constant error scores were of sufficient magnitude ($p < .001$) to withstand the maximum 10% increases that were reported by Wilson (1971) with moderate homogeneity violations. Reasons for these deviations were outlined below in the discussion on response strategies.

Information Load: Results obtained for the main effect of information load, or the number of movements to be recalled, were fully in accord with the first hypothesis that recall accuracy was inversely proportional to the information load. This finding was consistent with the results of Experiment II for the information load effect in that all levels differed from each other, except for 2 and 4 movements for absolute error scores. The use of the templated end point seemed to cause the differences between information loads of 2 and 4 movements, for constant and variable error scores, to have increased over what was reported by Sharp (1971) and in Experiment I. The mean absolute error scores for 2 and 4 movements just failed to reach significance at the 0.01 level but succeeded at the 0.05 level of confidence. The use of a physical end point, rather than a self-determined end point could be hypothesized to direct the Ss to attempt to monitor peripheral information rather than a central motor plan. If the fidelity of this information was not sufficiently organized to allow accurate movement, greater differences at all information loads would occur. It was also possible that the Ss responded according to an internal criterion of the movement in spite of the extent of the actual arm movements. This would have also caused errorful performance.

End Point: The results obtained for the main effect of end point for absolute, constant and variable error scores were indecisive in accepting the second hypothesis that no differences occurred between errors with a physical stop or with a self-terminated stop. The null hypothesis was confirmed by the constant and variable error analysis, but was rejected by the absolute error scores at the 0.01 level of confidence.

The fact that the constant error analysis did not reject the null hypothesis (Figure 12) was the result of a large overshooting tendency at low loads and an undershooting tendency at moderate and high loads. This differential response strategy across loads caused an information load by end point interaction effect that approached significance at the 0.05 level of confidence. The net effect of the overshooting and the undershooting was no end point effect for constant error analysis. The differential response strategy over levels of information loads, as reflected by constant error scores, could have caused the covariance deviations.

The overshooting which occurred at the lowest information load level for constant error scores and the general errorful performance for absolute error scores for the templated condition could have been predicted by the research of Taub and Berman (1968) or Greenwald (1970) which suggested a central form of monitoring of motor information. The assumption made by Pepper and Herman (1970) that "...an accurate memory trace...is initially stored" as a result of afferent motor input, seemed to be refuted by this investigation. If the information from the movement receptors was accurate and was being used, no differences should have occurred between recall in the templated end point condition and recall in the self-terminated end point condition.

The necessity of a theoretical framework to understand the movement information used in more complex motor behavior could be seen in light of these findings and in light of the prolific K STM research that has used physical end points.

Experiment IV

Hypotheses

Three hypotheses were formed in accordance with the related literature:

H_1: Errors for 2 movements $<$ Errors for 4 movements $<$ Errors for 8 movements for absolute, constant and variable error scores for both conditions of input.

H_2: Errors for self-determined input $<$ Errors for experimenter-determined input across all levels of information load for absolute, constant and variable error scores.

H_3: Errors for the first recall = Errors for the second recall across both conditions of input for absolute, constant and variable error scores.

In the first hypothesis, it was maintained that recall performance would deteriorate as the information load, or numbers of movements to be recalled, increased. This hypothesis was verified in the motor domain by Wilberg and Sharp (1970) and Sharp (1971) and generally by the results of Experiments I, II and III.

In the second hypothesis, performance in the self-controlled input condition was considered to be more accurate than in the experimenter-controlled condition, across all information loads. This hypothesis was based on the belief that the Ss must have attended more to the movement-produced afferent stimuli when the input was experimenter-controlled. It was hypothesized that, in the self-determined input condition, the Ss used well-learned central motor plans, rather than attending to low fidelity peripheral information and then acting upon it.

With the third hypothesis, it was intended to demonstrate that no differences would occur between the first and second recall trials. This hypothesis was stated in the null form because this had not been directly tested before and it was believed that the Ss were responding to a relatively stable central source of information. Experiments I and II, as well as the study by Sharp (1971), indicated that no forgetting occurred over unfilled intervals of 20 and 15 seconds, respectively.

Results

Preliminary Analysis: Three 3-way analyses of variance were computed on the absolute, constant and variable error scores using the Greenhouse and Geisser (1959) conservative degrees of freedom (Appendix D, Tables 31, 32 and 33, respectively). The null hypothesis was not rejected for any of the dependent variables at the 0.01 level of confidence.

Primary Analysis: Two 5-way analyses of variance and a 4-way analysis of variance were performed on the absolute, constant and variable error scores, respectively (Tables 10, 11 and 12). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test the main effects. The main effect of information load, or the number of movements recalled, was significant past the 0.01 level of confidence for absolute, constant and variable error scores. The main effect of successive recalls was not significant for any of the dependent variables at the 0.01 level of confidence. The main effect of method of input was significant at the 0.01 level of confidence for the absolute and constant error scores, but not for the variable error scores. There was also a main effects interaction significant at the 0.01 level of confidence, between number of movements recalled and the method of input for absolute and constant error scores. A significant replications effect at the 0.01 level was found to be significant for absolute and variable error scores at the 0.01 level of confidence.

Two analyses of variance were computed for simple main effects on the significant movement by input interaction for absolute and constant error scores (Appendix D, Tables 35 and 36). Significant differences at the 0.01 level were found between movement loads for both input conditions for absolute and constant error. Significant differences were also found between input conditions at the 0.01 level for 8 recalled movements for both absolute and variable error scores. No differences occurred between the 2 and 4 recalled movements for absolute and constant error scores at the 0.01 level of confidence.

Newman-Keuls Tests were calculated between the means of the levels of information load with all dependent variables for both self-controlled and experimenter-controlled inputs (Appendix D, Table 37). All experimenter-determined input conditions for information load differed from each other over all dependent variables at the 0.01 level of confidence. For self-determined input conditions no differences occurred between 2 and 4 movements for absolute error, but differences, significant at the 0.01 level of confidence, occurred between all other levels of information load for all of the dependent variables. One difference between 4 and 8 movements for variable error just failed to reach significance at the 0.01 level.

Discussion

Preliminary Analysis: Conclusions drawn from the primary analysis were believed to be legitimate, although the preliminary analysis failed to reach the 0.01 level of confidence using the most conservative degrees of freedom (Greenhouse and Geisser, 1959). The nature of the data was

TABLE 10

FIVE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	37496	2	18748.0	133.06**
Recalls (R)	84	1	84.0	.60
M x R	143	2	71.5	.51
Input (I)	6783	1	6783.0	48.45**
R x I	5	1	5.0	.04
M x I	6593	2	3296.5	23.50**
M x R x I	71	2	35.5	.25
Replications	2349	4	587.5	4.19**
Subjects	8778	11	798.0	5.70**
Pooled Error	97219	693	140.3	

TABLE 11

FIVE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	3765	2	1882.5	100.13**
Recalls (R)	1	1	1.0	.05
M x R	6	2	3.0	.16
Input (I)	166	1	166.0	8.83**
R x I	5	1	5.0	.27
M x I	1245	2	622.5	33.11**
M x R x I	0	2	0.0	0.00
Replications	127	4	31.8	1.69
Subjects	790	11	71.8	3.82**
Pooled Error	13038	693	18.8	

** significant at the 0.01 level

TABLE 12

FOUR WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	18.5	2	9.25	13.20**
Recalls (R)	.1	1	.1	.14
M x R	.2	2	.1	.14
Input (I)	1.2	1	1.2	1.70
R x I	.3	1	.3	.43
M x I	3.9	2	1.9	2.71
M x R x I	.3	2	.2	.29
Subjects	12.0	11	1.1	1.57
Pooled Error	81.3	121	.7	

** significant at the 0.01 level

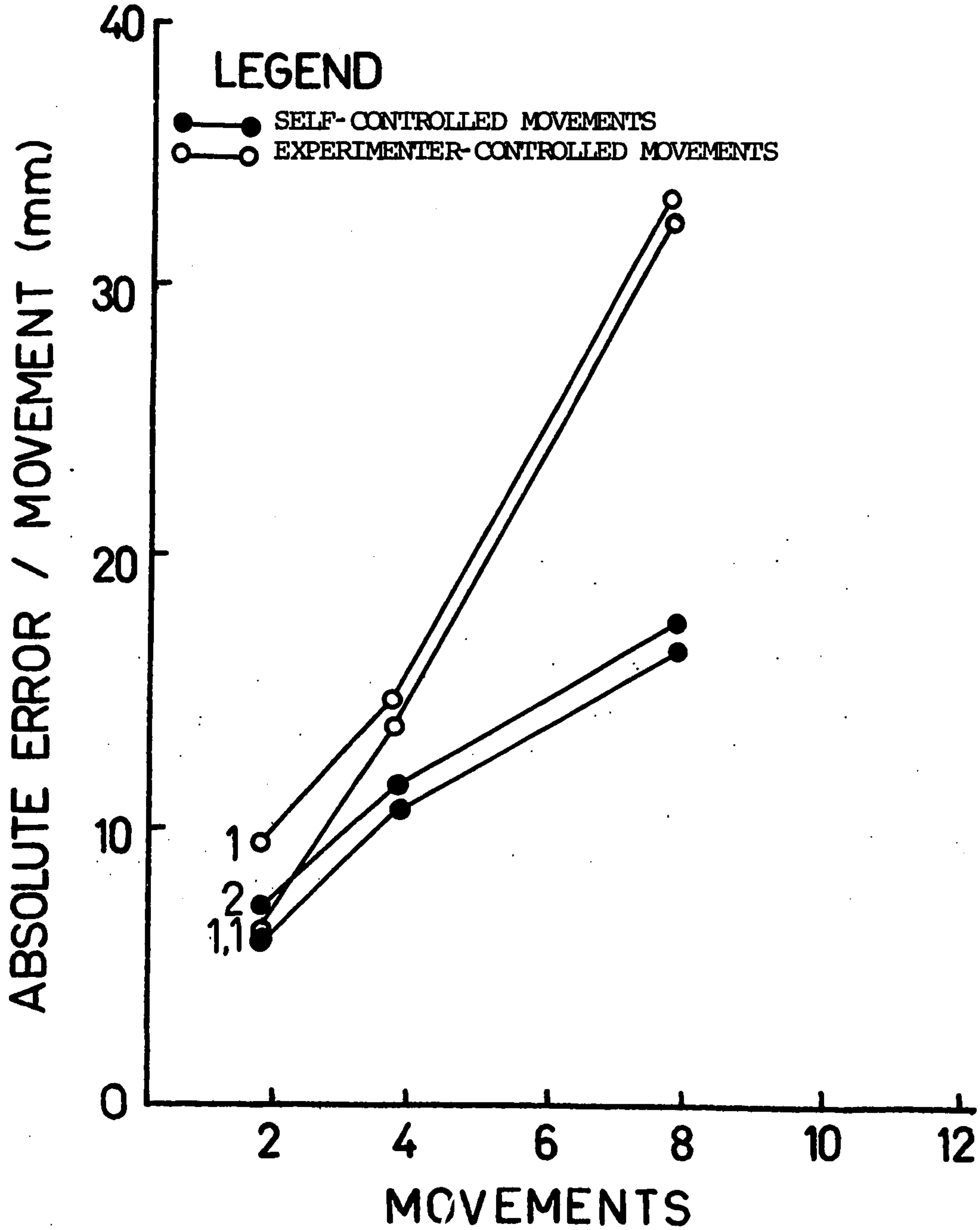

FIGURE 14 THE MEAN ABSOLUTE ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

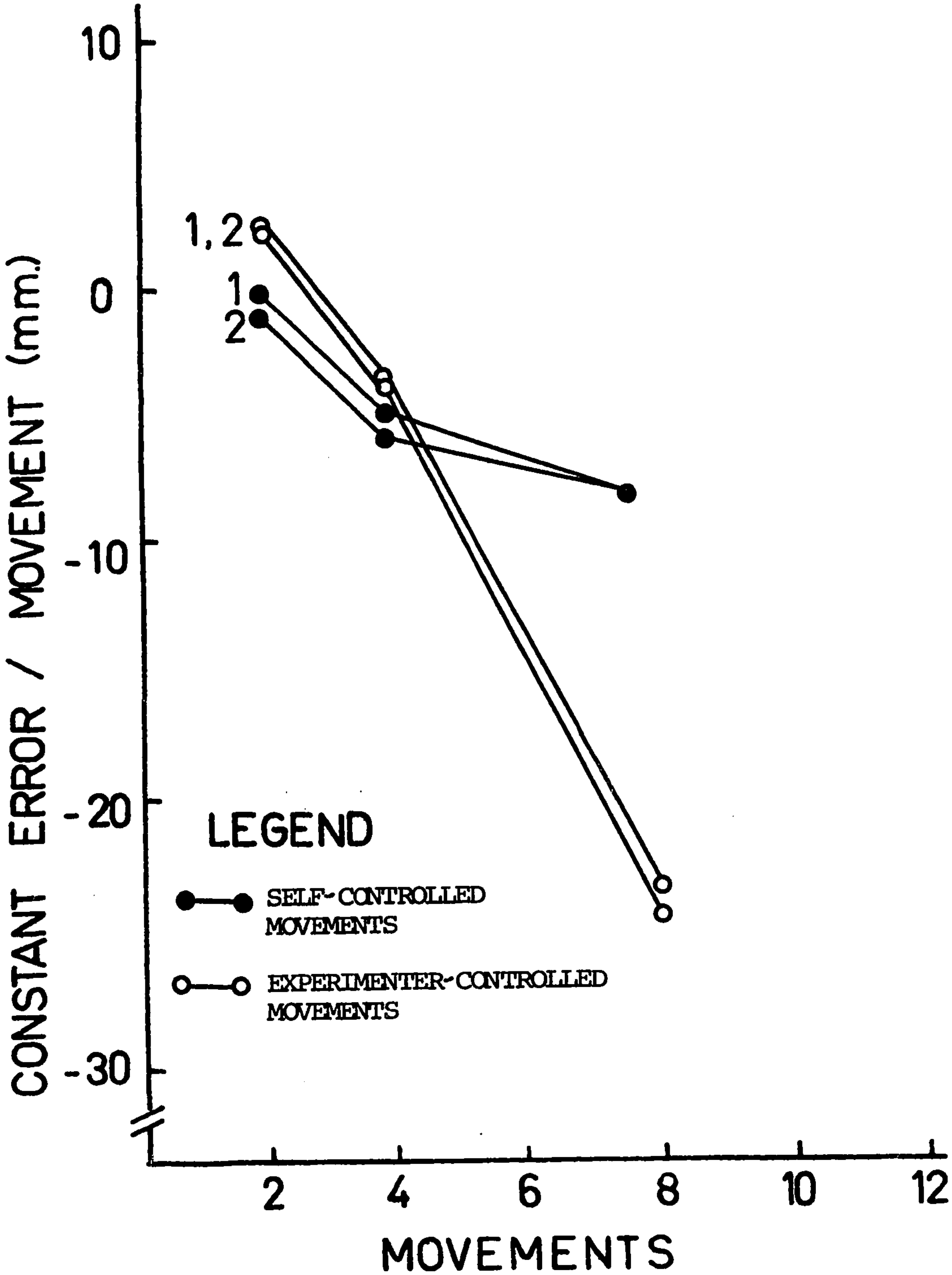

FIGURE 15 THE MEAN CONSTANT ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

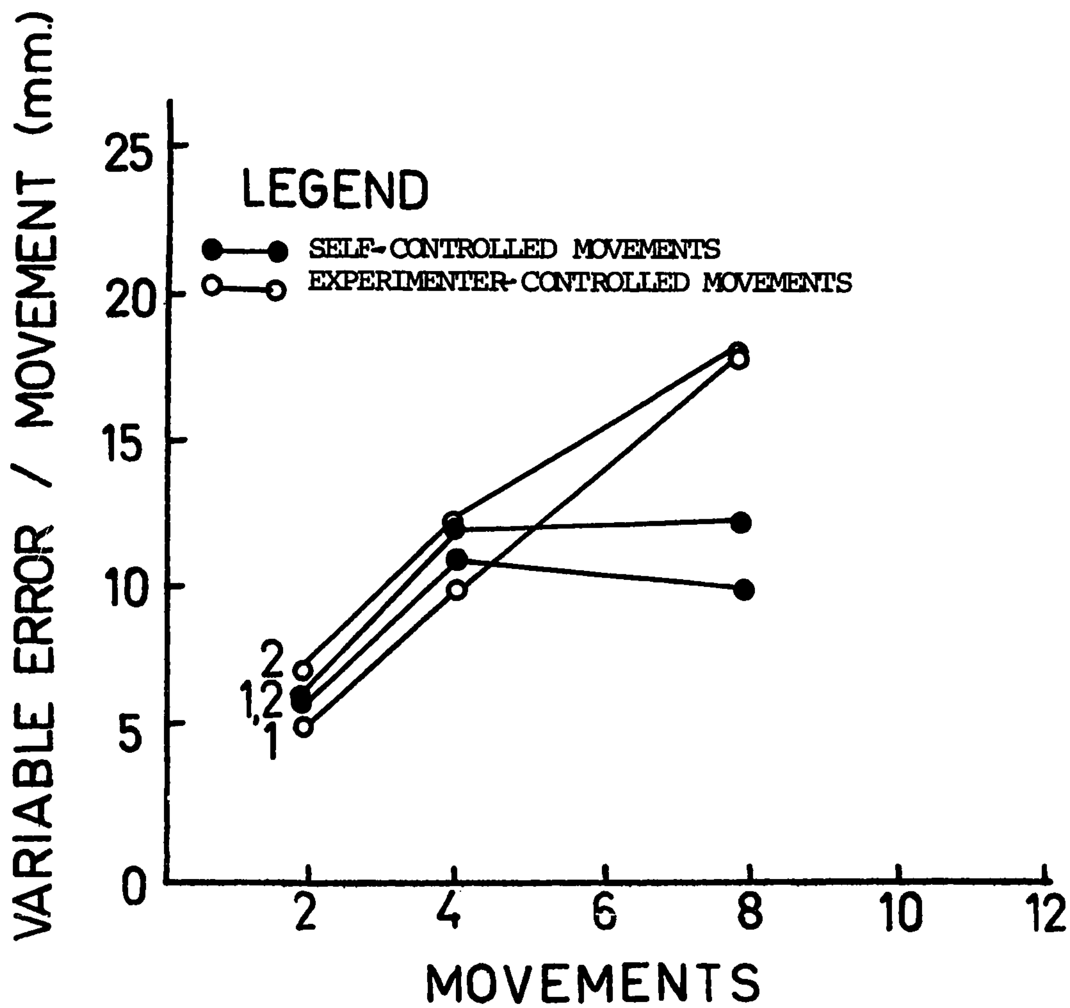

FIGURE 16 THE MEAN VARIABLE ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

not such that individual repeated pairs would polarize about 2 independent random variables. Wilson (1971) specified this criterion for the use of the most conservative test. Further, the conservative alpha levels for absolute and constant error scores reached and approached, respectively, the 0.01 level of confidence.

Information Load: The results obtained for the main effect of information load supported, for the most part, the first hypothesis that increased information load would result in decreased recall performance. The striking part of this finding was the replication of the main effects on both self-controlled and experimenter-controlled input with their counterparts in Experiments I and II. The absolute error scores for self-determined input failed to demonstrate differences in recall performance between 2 and 4 movements, similar to the findings in Experiment I, as well as those of Sharp's (1971) study. Similarly, differences occurred between all levels of information load for the experimenter-controlled input, as evidenced in Experiment II.

Input Modality: The results obtained from the main effect of input modality were consistent with the second hypothesis that the self-controlled input condition was more accurate than the experimenter-controlled condition. This hypothesis was supported, in the most part, for measures of absolute and constant error scores. This result seemed to lend further support to the idea that when the Ss were in the experimenter-controlled input condition, they were forced to attend to a source of peripheral information that could not be readily used for accurate recall performance. Posner and Konick (1966) and Posner (1967) indicated that this form of distance reproduction was inaccurate, while Wilberg (1969b) suggested that the information might not be decodable. Laabs (1971) also observed that movements that had reliable location cues had a visual component that was very accurate, while distance reproduction lacked that organizational component and was relatively inaccurate. The absence of an input effect for variable error was taken as evidence that the Ss responded consistently under both conditions. The response system was seen to be a reliable one; therefore, the fidelity and meaningfulness of the input used to initiate and direct the movement for accurate performance seemed to have caused the differential input effect.

Movement by Input Interaction: The significant movement by input interaction was an indication of the differential effect of movement input over the range of information loads. The lack of differences for 2 and 4 movements for the self-determined input condition lent support to the idea that the Ss were monitoring well-learned motor plans that were accurate up to 4 movements. The only conscious memory components for these movements might have been for the proper selection and initiation of a motor plan after which the movements were run off automatically.

The largest contributer to the main effect interaction was at the 8 movement level of information load. A dramatic change in recall performance occurred with the experimenter-controlled input condition. Performance breakdown at this level was due to the necessity for the Ss to attend to afferent motor input, rather than being able to focus attention on a well-learned sequence or series of sequences that might be usable as "subroutines" in the self-controlled condition. The review by Miller (1956) on memory span across different dimensions of input concluded that individuals seem to have a somewhat invariant capacity to process or hold in immediate memory 2.5 $\log_2$ or 7 errorless categories of information in the face of unpredictable information. For kinesthetic information, it seemed that an information load of 8 movements exceeded recall capacity when input was experimenter-controlled. It could not be determined with this analysis what information load the Ss could remember, but it could be predicted that performance breakdown would occur below 7 categories because of the suspected inaccuracies inherent in the afferent input. The reason performance did not break down at 8 movements with the self-determined input (as evidenced by the minimal change in slope in Figure 14) was that the movements were "chunked" (Miller, 1956) or reorganized into a more meaningful form.

Recall Consistency: The results obtained for the main effect of recall sequences were in accord with the third hypothesis. For all levels of input and all levels of information load no differences were found between the first and second recall. It seems, on the basis of the information provided them, whether from the "anticipated sensory feedback of the response" (Greenwald, 1970), from the peripheral kinesthetic information or from the instructions given, that the Ss made responses that could be easily reproduced at all information loads. Although the response itself was inaccurate from the view of "What the performer did," it was very accurate if measured by "What the performer tried to do" (Fitts and Posner, 1967). Therefore, the inaccuracy of the afferent kinesthetic information caused performance decrements by the selection of an improper response rather than the actual execution of the response.

Replications: The significant replications effect for absolute error was found to be without a trend that could have been a result of fatigue from the longer experimental sessions.

Experiment V

Hypotheses

Three hypotheses were formed in accordance with the related literature:

H_1: Errors for 2 movements $<$ Errors for 4 movements $<$ Errors for 8 movements for absolute, constant and variable error scores and for both conditions of input.

H_2: Errors for self-determined input $<$ Errors for experimenter-determined input for all levels of information load for absolute, constant and variable error scores.

H_3: Errors for the first recall = Errors for the second recall = Errors for the third recall = Errors for the fourth recall for absolute, constant and variable error scores.

In the first hypothesis, it was considered that recall performance would deteriorate as the information load, or number of movements recalled, increased. This hypothesis was verified by Wilberg and Sharp (1970) and Sharp (1971), as well as by the general findings of Experiments I, II, III and IV. One essential exception to this finding was that in no case in the above studies were differences detected between 2 and 4 movements when absolute error measures were taken and the Ss were asked to move "randomly" on their own.

The second hypothesis was formed to demonstrate that performance in the self-controlled input condition would be more accurate than in the experimenter-controlled input condition, for all levels of information load. This exact hypothesis was defended and upheld for absolute error scores in Experiment IV and it seemed improbable that it would be rejected in this investigation.

With the third hypothesis, it was predicted that no differences would occur among the 4 recall trials. This hypothesis was based upon the belief that the Ss used a stable central response system, rather than continually referring to peripheral movement trace that was susceptible to recall decrements if multiple recalls were required. This hypothesis was upheld in Experiment IV using 2 recalls.

Results

Preliminary Analysis: Three 3-way analyses of variance were performed on the absolute, constant and variable error scores using the Greenhouse and Geisser (1959) conservative degrees of freedom (Appendix E, Tables 38, 39 and 30). The null hypothesis was rejected for the absolute error scores at the 0.05 level while the constant error scores reached the 0.10 level of confidence. The null hypothesis for the variable error scores was rejected at the 0.10 level of confidence.

Primary Analysis: Two 5-way analyses of variance and a 4-way analysis of variance were calculated on the absolute, constant and variable error scores, respectively (Tables 13, 14 and 15). A pooling procedure after Paull (1950) was used to determine the best estimate of experimental error to test the main effects. The main effects of information load, or number of movements recalled, and method of input were significant well beyond the 0.01 level of confidence for all dependent variables. The main effects interaction for movements by input was also significant past the 0.01 level for absolute and constant error only. The main effect for recall consistency was not significant at the 0.01 level. The replications effect was significant only for absolute error at the 0.01 level and the subjects effect was significant at the 0.01 level of confidence for all dependent variables.

Two analyses of variance were computed for the simple main effects on the movements by input interaction for absolute and constant error scores (Appendix E, Tables 42 and 43). Significant differences at the 0.01 level were also found between both input conditions for 8 recall movements for both dependent variables. Differences were also found significant at the 0.01 level of confidence between input conditions for 4 movements for absolute error scores. No differences were found between the 2 input conditions for 2 movements at the 0.01 level for both dependent variables nor between 4 movements for the constant error scores.

Newman-Keuls Tests were calculated between the means of the levels of information load with all dependent variables for both self-controlled and experimenter-controlled inputs (Appendix E, Table 44). Significant differences at the 0.01 level occurred between all levels of movement load for all dependent variables and for both forms of input, except between 2 and 4 movements for self-controlled input when measured by absolute error scores.

Discussion

The factors and levels of factors studied in this investigation were identical to those of Experiment IV except that the number of recalls was increased from 2 to 4. The significant main effects of this investigation were identical to those of Experiment IV. For fuller discussions on each factor the reader is directed to the same section in the previous experiment. The main discussion in this chapter dealt with the effect of recalling the criterion trial more than once.

Preliminary Analysis: A decision was made by this writer that, on the basis of the alpha levels of 0.05 and 0.10 reached by the absolute and constant error scores for the effect of information load with the conservative test, and on the nature of the data, the use of the conventional

TABLE 13

FIVE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	76616	2	38308.0	354.70**
Recalls (R)	639	3	213.1	1.97
M x R	227	6	37.9	.35
Input (I)	11487	1	11487.0	106.36**
R x I	181	3	60.4	.56
M x I	5673	2	2836.2	26.26**
R x M x I	132	6	22.0	.20
Replications	1523	4	380.8	3.52**
Subjects	14494	11	1317.6	12.20**
Pooled Error	152639	1401	108.0	

TABLE 14

FIVE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	6686	2	3343.0	221.39**
Recalls (R)	7	3	2.3	.15
M x R	37	6	6.1	.40
Input (I)	284	1	284.0	18.81**
R x I	18	3	6.0	.40
M x I	1113	2	566.3	37.50**
R x M x I	32	6	5.3	.35
Replications	62	4	15.6	1.03
Subjects	1060	11	96.4	6.38**
Pooled Error	21167	1401	15.1	

** significant at the 0.01 level

TABLE 15

FOUR WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	41.1	2	20.5	68.33**
Recalls (R)	.5	3	.2	.66
M x R	2.8	6	.5	1.66
Input (I)	7.6	1	7.6	25.33**
R x I	.2	3	.1	.33
M x I	1.9	2	.9	3.00
R x M x I	1.0	6	.2	.66
Subjects	11.8	11	1.1	3.60**
Pooled Error	72.5	253	.3	

** significant at the 0.01 level

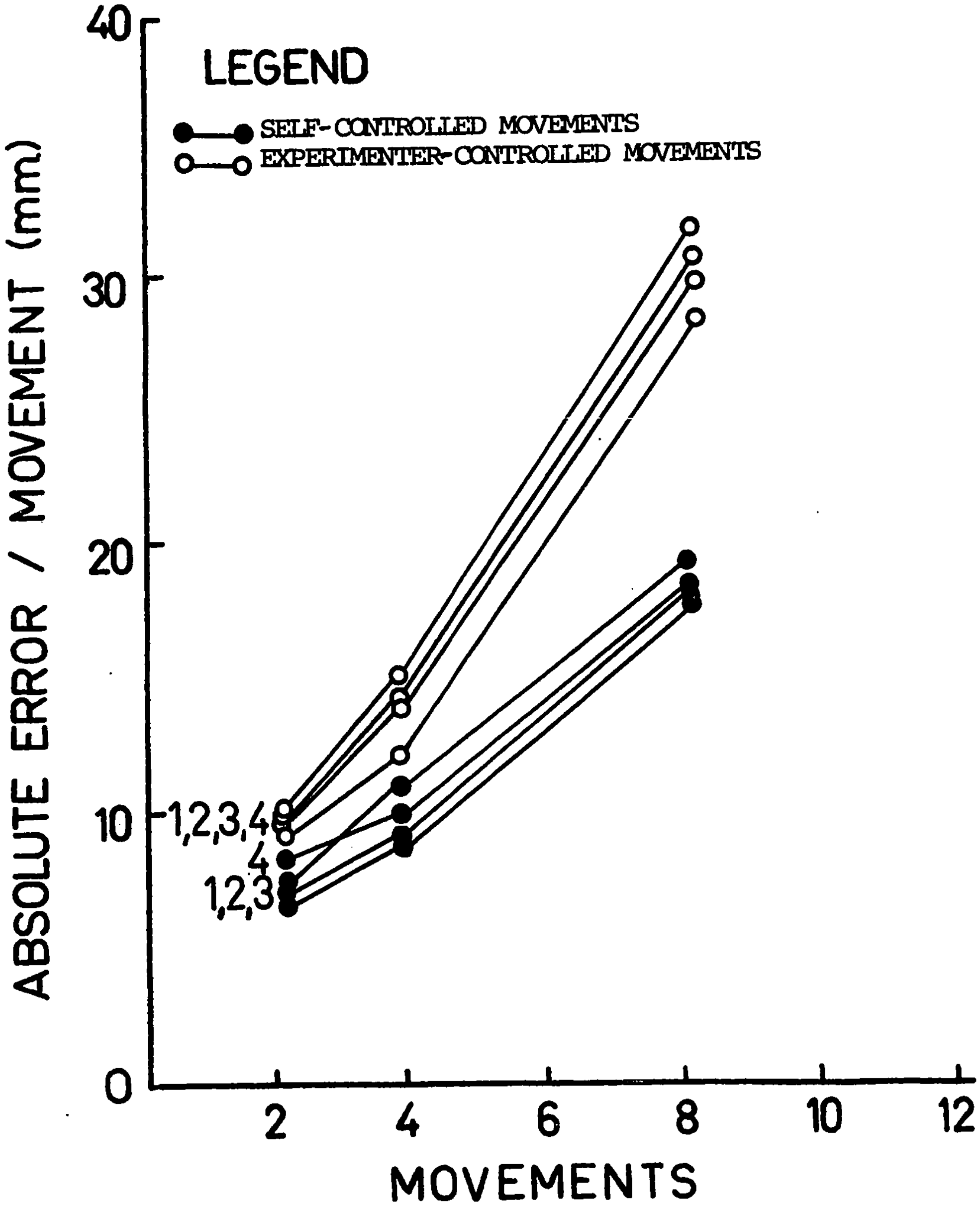

FIGURE 17 THE MEAN ABSOLUTE ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

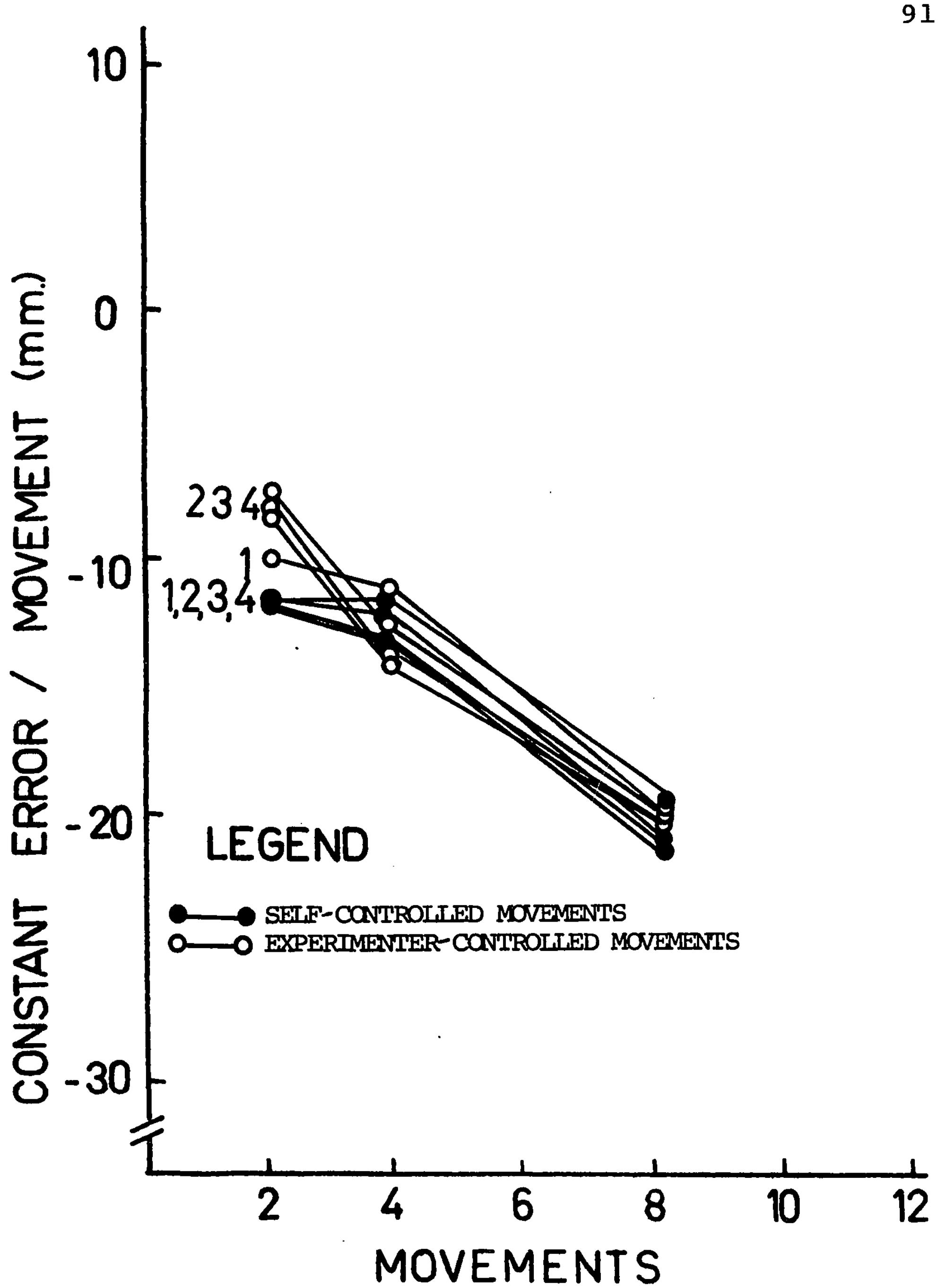

FIGURE 18 THE MEAN CONSTANT ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

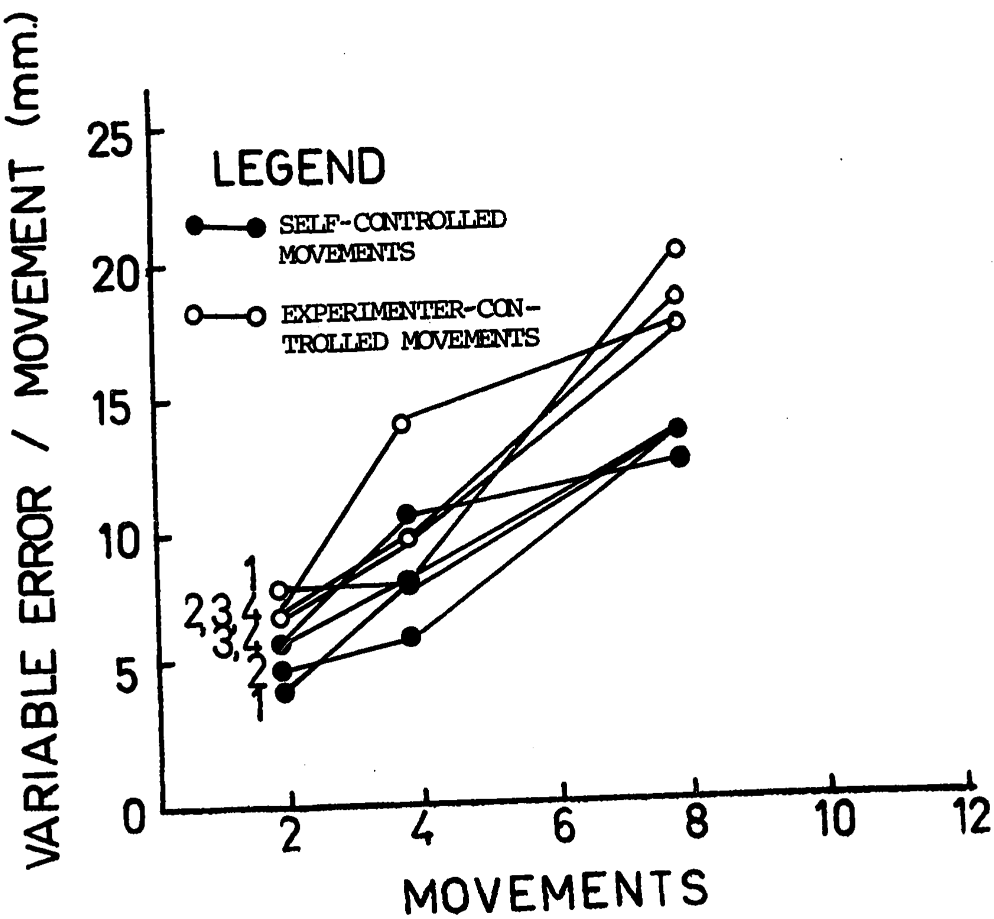

FIGURE 19 THE MEAN VARIABLE ERROR FOR THE NUMBER OF MOVEMENTS AND THE NUMBER OF RECALLS WITH EXPERIMENTER-CONTROLLED AND SELF-CONTROLLED MOVEMENTS

degrees of freedom was warranted for the primary analysis.

Information Load: The results obtained for the main effect of information load were fully in agreement with the first hypothesis that increasing the information load would increase decrements in recall performance.

Input: The results obtained for the main effect of method input were in accordance with the second hypothesis. Again these results paralleled those of Experiment IV, except that in this case the significant differences due to the method of movement input were found for the variable error scores at the 0.01 level. The increased variability about the constant scores may have been due to fatigue in the Ss because of prolongation of the experiment by the use of 4 recall trials.

Information Load by Input Interaction: Similar results to those of Experiment IV were found regarding the movement by input interaction, except for the significant difference at the 0.01 level found between input conditions for 4 movements with absolute error scores. The consistent finding that no differences occurred between 2 and 4 movements for self-determined input, as measured by absolute error, was replicated again.

Recall Consistency: The results obtained for the main effect of recall were in accordance with the third hypothesis that no differences would occur between any of the 4 recall trials. The total time that the Ss were forced to maintain and recall the required movements for an information load of 8 was approaching 1 minute. It is the opinion of this writer that the Ss must have used a stable central source of information which would initiate a series of responses. Pepper and Herman (1970) hypothesized that the movement trace was susceptible to spontaneous decay as well as to interference effects that caused changes in response bias due to "muscle tension." This maleable trace concept of the movement did not seem to be supported by the consistency of the responses with both forms of input. The overshooting with repeated recalls, found by Stelmach and Bassin (1971), was also not found. The inaccuracy of the experimenter-controlled input condition at the 8 movement level, as compared to the self-controlled condition, was striking in that the recall trials for both input conditions were consistent. It was therefore hypothesized that, based on the quality of information, a response strategy was selected and acted upon. In the experimenter-controlled condition the Ss were forced to attend to the peripheral information and make a response based on that condition. The inaccuracy of that response, compared to the self-controlled input condition, at high information loads indicated that the information received from the periphery was not of sufficient fidelity or meaningfulness to allow accurate selection of a response sequence. The fact that no recall effects occurred could be interpreted to mean that a stable response mode had been selected. For the experimenter-controlled input condition, it could be considered that an accurate response was made to an unreliable source of information. It does not seem tenable that the S attended any longer to the afferent trace once a response had been selected.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The purpose of this series of studies was to determine, across a wide variety of experimental tasks, the nature of the movement information that was being used in a motor STM paradigm. Specifically, it was of primary interest to infer the relative roles of peripheral movement input and centrally stored movement input in making responses that varied in information load. The experimental design was a treatment by subjects, factorial design with repeated measures and 5 replications for each subject. Ss were 12 undergraduate and graduate physical education students between the ages of 19 and 26.

The apparatus consisted of a joystick attached to two potentiometers which acted as the axes of movement as well as movement transducers. The experimental task was for the S to establish a given number of movements under different constraints and then reproduce them sometime later.

There were 6 factors of experimental interest:

information load with 5 levels (2, 4, 8, 10 and 12 locations) axis of movement with 2 levels (alignment and compensation), recall delay with 2 levels (immediate and rest for 20 seconds), end point with 2 levels (free and templated end points), method of movement input with 2 levels (self-determined and experimenter-determined input) and recall consistency with 2 levels (2 and 4 recalls). All factors were analysed using the dependent variables of absolute error, constant error and variable error scores.

The findings of the 5 related studies were as follows:

In Experiment I, it was found that increase information load caused decreased recall accuracy where the Ss movements were self-determined. The magnitude of these errors, however, were not as large at very high information loads as those predicted from other research using different input modalities. It was believed that the responses were made using well-learned movement routines. Further, it was found that no decrements in recall occurred after a rest interval indicating that this information source was stable.

In Experiment II, a reduced information load was used and the movement input was experimenter-determined. This latter technique caused greater recall decrements than had been observed in Experiment I where the input movements were self-determined. This decrease in response accuracy was believed to have resulted from directing the Ss attention to peripheral movement-produced stimuli that could not be used accurately for later recall. Again, delayed recall was as accurate as immediate recall.

In Experiment III, the accuracy of self-terminated movements was compared to that of movements that were terminated by a physical stop. Overall, it was found that movements that were self-terminated were more accurate than movements that were externally-terminated. This indicated that when the Ss attention was directed to peripheral movement-produced information, inaccurate responses resulted.

In Experiments IV and V, the effect of repeatedly recalled responses for self-determined and experimenter-determined movements were observed. It was found that self-determined movements were recalled more accurately than experimenter-determined movements at high information loads. Furthermore, it was found that whatever the method of input, multiple recalls were very consistent. It was believed that, based on whatever the form of input, a response from a very stable and accurate source was selected and initiated. The fidelity of the source of information and the subsequent response accuracy was believed to be high if central information was monitored and low if peripheral information was attended to.

Conclusions

Based upon the above results, no definite conclusions could be reached, but the following observations were tentatively offered:

In a kinesthetic STM paradigm the performer appeared to optimize on the information available to him in order to make an appropriate response. Unless specifically constrained, recall seemed to be based upon efferent information available to the performer, rather than the peripheral kinesthetic information that resulted from ovement. This efferent response information tended to resist spontaneous decay and could be used accurately for multiple recalls.

Performance decrements increased when the performer was constrained to respond with afferent kinesthetic information. It was believed that this information was not sufficiently organized to allow accurate response selection.

BIBLIOGRAPHY

Adams, Jack A. Human Memory, New York: McGraw-Hill, 1967.

Adams, Jack A. and Dijkstra, Sanne. "Short term memory for motor responses," Journal of Experimental Psychology, 1966, 71, 314-318.

Anderson, Nancy S. "Poststimulus cuing in immediate memory," Journal of Experimental Psychology, 1960, 60, 216-221.

Attneave, Fred. Applications of Information Theory to Psychology. Holt, Rinehart and Winston: New York, 1959.

Baddeley, A. D. "Short-term memory for word sequences as a function of acoustic, semantic and formal similarity," Quarterly Journal of Experimental Psychology, 1966, 18, 362-365.

Boulter, Lawrence R. "Evaluation of mechanisms in delay of knowledge of results," Canadian Journal of Psychology, 1964, 18, 281-291.

Brindley, G. S., "The use made by the cerebellum of the information that it receives from the sense organs," International Brain Research Organizational Bulletin, 1964, 3, 80.

Carre, Frank Alexander. "Increasing torque as a kinesthetically dependent variable in short-term memory," Unpublished M.A. Thesis, Faculty of Physical Education, University of Alberta, 1969.

Clarke, H. J. "Recognition memory for random shapes as a function of complexity, association value and decay," Journal of Experimental Psychology, 1965, 69, 590-595.

Conrad, R. "Acoustic confusions in immediate memory," British Journal of Psychology, 1964, 55, 75-84.

Dukes, Warren. "The effect of direction, pause and rest on a replacement accuracy task," Unpublished M.Sc. Thesis, Faculty of Physical Education, University of Alberta, 1970.

Fisher, R. A. and Yates, F. Statistical Tables for Biological, Agricultural and Medical Research, Edinburgh, Oliver and Boyd, 1948.

Fitts, Paul M. and Posner, Michael I. Human Performance, Brooks-Cole, Belmont, Calif., 1967.

Glickman, S. E. and Schiff, B. B., "A biological theory of reinforcement," Psychological Review, 1967, 74, 81-109.

Greenhouse, S. W. and Geisser, S., "On methods in the analysis of profile data," Psychometrika, 1959, 24, 95-112.

Greenwald, Anthony G. "Sensory feedback mechanisms in performance control: with special reference to the ideomotor mechanism," Psychological Review, 1970, 77, 73-99.

Haber, R. N. "Effects of coding strategy on perceptual memory," Journal of Experimental Psychology, 1964, 68, 357-62.

Hebb, Donald O. "Concerning Imagery," Psychological Review, 1968, 75, 466-77.

Hughes, M. J. "Visual and kinesthetic short-term memory of a constant weight load," Unpublished M.Sc. Thesis, Faculty of Physical Education, University of Alberta, 1969.

James, William. Principles of Psychology. Vol. 1 and 2, New York: Holt, 1890.

Konorski, Jerzy. Integrative Activity of the Brain. New York: University of Chicago Press, 1967.

Laabs, G. J. "Cue effects in motor STM," Unpublished Ph.D. Dissertation, Department of Psychology, University of Oregon, 1971.

McClements, J. D. "Recall of movement distance and starting position from short-term memory," Unpublished M.Sc. Thesis, Faculty of Physical Education, University of Alberta, 1969.

McLane, A. S. and Hoag, J. E. "The curve of forgetting in the first three minutes," American Journal of Psychology, 1943, 56, 105-110.

Merton, P. A. "Human position sense and sense of effort," Symposium of the Society for Experimental Biology, 1964, 18, 387-400.

Miller, G. A. "Magical number seven--plus or minus two," Psychological Review, 1956, 63, 81-97.

Moyst, Victor Herbert. "Visual and kinesthetic short-term memory in a free-moving-load system," Unpublished M.Sc. Thesis, Faculty of Physical Education, University of Alberta, 1969.

Norrie, Mary Lou. "Short-term memory trace decay in kinesthetically monitored force reproduction," Research Quarterly, 1968, 39, 640-646.

Paull, A. E., "On a preliminary test for pooling mean squares in the analysis of variance," Annals of Mathematical Statistics, 1950, 21, 539-556.

Pepper, Ross L. and Herman, Louis M. "Decay and interference effects in the short-term retention of a discrete motor act," Journal of Experimental Psychology, 1970, 83, 2 .

Posner, Michael I. "Immediate memory in sequential tasks," Psychological Bulletin, 1963, 60, 333-349.

________. "Components of skilled performance," Science, 1966, 152, 1712-8.

________. "Characteristics of visual and kinesthetic memory codes," Journal of Experimental Psychology, 1967(a), 75, 103, 107.

________. "Short-term memory systems in human information processing," Acta Psychologica, 1967(b), 27, 267-284.

Posner, Michael I. and Konick, Andrew F. "Short-term retention of visual and kinesthetic information," Organizational Behavior and Human Performance, 1966, 1, 71-86.

Postman, Leo. "Short-term memory and incidental learning," In A. W. Melton (Ed.) Categories of Human Learning, New York, Academic Press, 1964.

Poulton, E. C., "Sequential short-term emeory: Some tracking experiments," Ergonomics, 1963, 6, 518-522.

Riley, D. A. "Memory for form," In L. Postman(ed.) Psychology in the Making, New York: Knoff, 1962.

Sharp, Robert Harold. "Processing demands of kinesthetic information in short-term memory," Unpublished M.A. Thesis, Faculty of Physical Education, University of Alberta, 1971.

Siddal, D. J., Holding, D. H. and Draper, J. "Errors of arm and extent in mahual point to point movement," Occupational Psychology, 1957, 31, 185-195.

Sperling, G. "Successive approximations to a model for short-term memory," Acta Psychologica, 1967, 27, 285-292.

Stelmach, George E. "Short-term motor retention as a function of response-similarity," Journal of Motor Behavior, 1969, 1, 37-44.

________. "Kinesthetic recall and information reduction activity," Journal of Motor Behavior, 1970, 2, 183-194.

Stelmach, George E. and Bassin, Stanley L. "The role of overt motor rehearsal in kinesthetic recall," Acta Psychologica, 1971, 35, 56-63.

Taub, Edward and Berman, A. J. "Movement learning in the absence of sensory feedback," In S. J. Freedman (ed.) The Neuropsychology of Spatially Oriented Behavior, Homewood, Illinois: Dorsey Press, 1968.

Vanderwolf, C. H., "Hippocampal electrical activity and voluntary movement in the rat," Electroencephalography and Clinical Neurophysiology, 1969, 30, 407-418.

Wickelgren, W. A. "Acoustic similarity and intrusion errors in short-term memory," Journal of Experimental Psychology, 1965, 70, 102-108.

________. "Phonetic similarity and interference in short-term memory for single letters," Journal of Experimental Psychology, 1966, 71, 396-404.

Wilberg, R. B., "Human performance theory and design," Canadian Association of Health, Physical Education and Recreation Journal, 1969(a), 36, 17-19 & 38.

________. "Response accuracy based upon recall from visual and kinesthetic short-term memory," Research Quarterly, 1969(b), 40, 407-414.

________. "End point control in kinesthetic STM," Unpublished Study, Faculty of Physical Education, University of Alberta, 1971.

Wilberg, R. B. and Sharp, R. H. "Differential interpolated information processing in kinesthetic short-term memory," Unpublished Study, University of Alberta, 1970.

Wilson, K., "The sampling distributions of conventional, conservative and corrected F ratios in repeated measures designs with heterogeneity of covariance," Unpublished Paper, Department of Computing Science, University of Alberta, 1971.

APPENDIX A

TABLE 16

THREE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	4	1	45292.3	2.78
Delay (D)	1	1	209.2	.01
M x D	4	1	542.5	.03
Axis (A)	1	1	617.8	.04
M x A	4	1	630.9	.04
D x A	1	1	.1	.00
M x D x A	4	1	221.9	.01
Error	1180	11	16285.6	

TABLE 17

THREE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	4	1	32691.0	2.13
Delay (D)	1	1	62.1	.00
M x D	4	1	500.4	.03
Axis (A)	1	1	1589.3	.10
M x A	4	1	258.5	.02
D x A	1	1	44.5	.00
M x D x A	4	1	457.1	.03
Error	1180	11	15284.9	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 18

THREE WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	4	1	130.3	1.6
Delay (D)	1	1	.7	.0
M x D	4	1	11.3	.1
Axis (A)	1	1	4.8	.1
M x A	4	1	23.0	.3
D x A	1	1	8.2	.1
M x D x A	4	1	16.3	.2
Error	220	11	81.4	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 19

MEANS FOR NUMBER OF MOVEMENTS, DELAY INTERVAL AND MOVEMENT AXIS FOR ABSOLUTE, CONSTANT AND VARIABLE ERROR SCORES

	Recall Delay		Movements				
			2	4	8	10	12
absolute error	immediate	(X)	76.3	101.5	154.7	209.3	204.2
	delay	(X)	79.0	108.5	101.3	193.0	246.0
	immediate	(Y)	68.7	104.7	178.2	225.8	240.5
	delay	(Y)	80.8	100.8	205.0	218.5	254.3
constant error	immediate	(X)	2.0	1.1	-6.0	-11.7	-10.3
	delay	(X)	1.6	-.8	-8.0	-9.9	-12.6
	immediate	(Y)	.6	-4.9	-7.4	-12.5	-14.0
	delay	(Y)	-.5	-3.1	-10.5	-12.0	-12.5
variable error	immediate	(X)	5.6	6.9	9.1	10.3	12.4
	delay	(X)	8.9	9.5	9.4	10.6	10.0
	immediate	(Y)	4.8	10.2	10.8	15.3	13.5
	delay	(Y)	4.4	6.4	12.4	10.8	12.9

X = alignment
Y = compensation

TABLE 20

NEUMAN-KEULS TESTS APPLIED TO DIFFERENCES BETWEEN K=5 MEANS FOR NUMBER OF MOVEMENTS FOR ABSOLUTE , CONSTANT AND VARIABLE ERROR SCORES

ABSOLUTE ERROR

	Movements					
	2	4 4	8	10	12	Shortest Significant Ranges (.01)
Means	7.6	10.4	17.8	21.2	23.6	
7.6		2.8	10.2**	13.6**	16.0**	W_2= 8.0
10.4			7.4	9.8**	13.2**	W_3= 9.1
17.8				3.4	5.8	W_4= 9.7
21.2					2.4	W_5=10.1

CONSTANT ERROR

	Movements					
	12	10	8	4	2	Shortest Significant Ranges (.01)
Means	-12.3	-11.5	-8.0	-2.0	.9	
-12.3		.8	4.3**	10.3**	13.2**	W_2= 2.7
-11.5			3.5**	9.5**	12.4**	W_3= 3.1
- 8.0				6.0**	8.9**	W_4= 3.3
- 2.0					2.9	W_5= 3.4

VARIABLE ERROR

	Movements					
	2	4	8	10	12	Shortest Significant Ranges (.01)
Means	5.9	8.2	10.4	11.8	12.2	
5.9		2.3**	4.5**	5.9**	6.3**	W_2= 1.0
8.2			2.2**	3.6**	4.0**	W_3= 1.2
10.4				1.4**	1.8**	W_4= 1.2
11.8					.4	W_5= 1.3

** significant at the 0.01 level

APPENDIX B

TABLE 21

TWO WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	23141.0	3.67
Delay (D)	1	1	57.0	.01
M x D	2	1	17.0	.00
Error	354	11	6308.8	

TABLE 22

TWO WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	2274.0	2.77
Delay (D)	1	1	8.0	.01
M x D	2	1	17.0	.00
Error	354	11	820.4	

TABLE 23

TWO WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	13.0	3.94
Delay (D)	1	1	0.0	.00
M x D	2	1	0.0	.00
Error	36	11	3.3	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 24

MEANS FOR NUMBER OF MOVEMENTS AND DELAY
FOR ABSOLUTE, CONSTANT AND VARIABLE ERROR
WITH VISUALLY GUIDED INPUT

	Recall Delay	Movements		
		2	4	8
absolute error	immediate	10.2	16.2	29.9
	delay	11.4	17.2	30.1
constant error	immediate	1.7	-5.0	-18.7
	delay	-.4	-6.3	-18.2
variable error	immediate	7.6	13.8	15.8
	delay	7.8	14.2	20.3

TABLE 25

NEUMAN-KEULS TESTS APPLIED TO DIFFERENCES BETWEEN K=3 MEANS FOR NUMBER OF MOVEMENTS FOR ABSOLUTE , CONSTANT AND VARIABLE ERROR SCORES (EXPERIMENTER CONTROLLED INPUT)

ABSOLUTE ERROR

	Movements			Shortest Significant Ranges (.01)
	2	4	8	
Means	10.2	16.7	30.0	
10.8		5.9**	29.2**	W_2= 4.0
16.7			13.3**	W_3= 4.5

CONSTANT ERROR

	Movements			Shortest Significant Ranges (.01)
	8	4	2	
Means	-18.4	-5.6	.7	
-18.4		12.8**	19.1**	W_2= 1.45
- 5.6			6.1**	W_3= 1.65

VARIABLE ERROR

	Movements			Shortest Significant Ranges (.01)
	2	4	8	
Means	7.7	14.0	18.1	
7.7		6.3**	10.4**	W_2= .47
14.0			4.1**	W_3= .54

** significant at the 0.01 level

APPENDIX C

TABLE 26

TWO WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	9135.0	2.33
End Point (E)	1	1	3234.0	.83
M x E	2	1	313.0	.08
Error	294	9	3919.7	

TABLE 27

TWO WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	866.0	1.92
End Point (E)	1	1	8.0	.02
M x E	2	1	79.0	.18
Error	294	9	452.1	

TABLE 28

TWO WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	5.0	2.08
End Point (E)	1	1	2.0	.83
M x E	2	1	.0	.0
Error	54	9	2.4	

xx significant at the 0.01 level Greenhouse ans Geisser

TABLE 29

MEANS FOR NUMBER OF MOVEMENTS AND TYPE OF END POINT FOR ABSOLUTE, CONSTANT AND VARIABLE ERROR

	End Point	Movements		
		2	4	8
absolute error	free	6.6	9.8	17.4
	template	10.9	16.2	26.6
constant error	free	.3	-2.2	-9.2
	template	3.8	-5.0	-13.0
variable error	free	4.1	7.7	10.9
	template	7.2	12.0	14.4

TABLE 30

NEWMAN-KEULS TESTS APPLIED TO DIFFERENCES BETWEEN K=3 MEANS FOR NUMBER OF MOVEMENTS FOR ABSOLUTE , CONSTANT AND VARIABLE ERROR SCORES

ABSOLUTE ERROR

	Movements			
	2	4	8	Shortest Significant Ranges (.01)
Means	8.8	13.8	22.0	
8.8		4.2	13.2**	W_2= 4.4
13.0			9.0**	W_3= 4.9

CONSTANT ERROR

	Movements			
	8	4	2	Shortest Significant Ranges (.01)
Means	-11.1	-3.9	2.1	
-11.1		7.2**	13.2**	W_2= 1.6
- 3.9			6.0**	W_3= 1.7

VARIABLE ERROR

	Movements			
	2	4	8	Shortest Significant Ranges (.01)
Means	5.7	9.9	12.7	
5.7		4.2**	6.0**	W_2= .62
9.9			2.8**	W_3= .70

** significant at the 0.01 level

APPENDIX D

TABLE 31

THREE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	37496.0	3.81
Recalls (R)	1	1	84.0	.ol
M x R	2	1	143.0	.02
Input (I)	1	1	6783.0	.69
R x I	1	1	5.0	.00
M x I	2	1	6953.0	.67
M x R x I	2	1	72.0	.01
Error	708	11	9859.8	.01

TABLE 32

THREE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	3764.0	2.97
Recalls (R)	1	1	1.0	.00
M x R	2	1	6.0	.00
Input (I)	1	1	166.0	.13
R x I	1	1	5.0	.00
M x I	2	1	1245.0	.98
M x R x I	2	1	0.0	.00
Error	708	11	1268	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 33

THREE WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	19.58	1.58
Recalls (R)	1	1	0.0	.00
M x R	2	1	0.0	.00
Input (I)	1	1	1.0	.08
R x I	1	1	0.0	.00
M x I	2	1	4.0	.33
M x R x I	2	1	0.0	.00
Error	132	11	12.0	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 34

MEANS FOR NUMBER OF MOVEMENTS, NUMBER OF RECALLS AND TYPE OF INPUT FOR ABSOLUTE, CONSTANT AND VARIABLE ERROR

	Input	Recall Sequence	Movements		
			2	4	8
absolute error	self controlled	first	7.43	11.42	18.12
		second	8.32	12.77	18.45
	experimenter controlled	first	7.88	14.37	33.65
		second	10.07	15.15	32.22
constant error	self controlled	first	-0.20	-3.20	-8.50
		second	-1.20	-4.50	-8.40
	experimenter controlled	first	2.90	-1.70	-23.80
		second	2.80	-1.80	-22.70
variable error	self controlled	first	6.00	11.00	10.00
		second	6.00	12.00	12.00
	experimenter controlled	first	5.00	12.00	18.00
		second	7.00	10.00	18.00

TABLE 35

ANALYSIS OF VARIANCE FOR SIMPLE MAIN EFFECTS
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	37496	2	18748.0	133.91**
M at I_f	6581	2	3290.5	23.42**
M at I_v	12895	2	6447.5	46.01**
Input (I)	6783	1	6783.0	48.34**
I at M_2	74	1	74.0	.53
I at M_4	407	1	407.1	2.90
I at M_8	12895	1	12895.0	91.91**
M x I	6593	2	3296.5	23.50**
Pooled Error	97219	693	140.3	

TABLE 36

ANALYSIS OF VARIANCE FOR SIMPLE MAIN EFFECTS
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	3764	2	1882.0	100.13**
M at I_f	360	2	180.0	9.57**
M at I_v	4650	2	2325.0	123.67**
Input (I)	166	1	166.0	8.83**
I at M_2	80	1	80.0	4.25*
I at M_4	30	1	30.0	1.59
I at M_8	130	1	130.0	6.90**
M x I	1245	2	622.5	33.11**
Pooled Error	13038	693	18.8	

** significant at the 0.01 level
* significant at the 0.05 level

TABLE 37

NEWMAN-KEULS TESTS APPLIED TO DIFFERENCES BETWEEN K=3 MEANS FOR NUMBER OF MOVEMENTS

ABSOLUTE ERROR

Movements (self-controlled)

	2	4	8	Shortest Significant Ranges
Means	7.5	10.0	19.8	(.01)
7.5		2.5	12.3**	W_2= 3.5
10.0			9.8**	W_3= 3.9

Movements (experimenter-controlled)

	2	4	8	Shortest Significant Ranges
Means	9.2	13.8	30.9	(.01)
9.2		4.6**	21.7**	W_2= 3.5
13.8			17.1**	W_3= 3.9

CONSTANT ERROR

Movements (self-controlled)

	8	4	2	Shortest Significant Ranges
Means	-10.0	-2.3	-.9	(.01)
-10.0		7.7**	9.1**	W_2= 1.29
- 2.3			1.4	W_3= 1.5

Movements (experimenter-controlled)

	8	4	2	Shortest Significant Ranges
Means	-20.5	-2.9	1.9	(.01)
-20.5		17.6**	19.6**	W_2= 1.29
- 2.9			1.0	W_3= 1.5

** significant at the 0.01 level

TABLE 37 (cont'd)

VARIABLE ERROR				
	Movements (self-controlled)			
	2	8	4	Shortest Significant Ranges (.01)
Means	6.0	11.0	11.5	
6.0		5.0**	5.5**	W_2= .7
11.0			.5	W_3= .7
	Movements (experimenter-controlled)			
	2	4	8	Shortest Significant Ranges (.01)
Means	6.0	11.0	18.0	
6.0		5.0**	12.0**	W_2= .7
11.0			1.0**	W_3= .7

** significant at the 0.01 level

APPENDIX E

TABLE 38

THREE WAY ANALYSIS OF VARIANCE
ABSOLUTE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	76616.0	5.00[x]
Recalls (R)	3	1	639.0	.04
M x R	6	1	227.0	.02
Input (I)	1	1	11486.0	.75
R x I	3	1	181.0	.02
M x I	2	1	5672.0	.37
R x M x I	6	1	132.0	.01
Error	1416	11	15332.0	

TABLE 39

THREE WAY ANALYSIS OF VARIANCE
CONSTANT ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	6686.0	3.29
Recalls (R)	3	1	70.0	.00
M x R	6	1	37.0	.02
Input (I)	1	1	284.0	.14
R x I	3	1	18.0	.01
M x I	2	1	1112.0	.55
R x M x I	6	1	32.0	.02
Error	1416	11	2060.0	

x significant at the 0.05 level Greenhouse and Geisser

TABLE 40

THREE WAY ANALYSIS OF VARIANCE
VARIABLE ERROR

Source	df	Conservative df	Mean Squares	F
Movements (M)	2	1	19.0	1.58
Recalls (R)	1	1	0.0	.00
M x R	2	1	0.0	.00
Input (I)	1	1	1.0	.08
R x I	1	1	0.0	.00
M x I	2	1	4.0	.33
R x M x I	2	1	0.0	.00
Error	132	11	12.0	

xx significant at the 0.01 level Greenhouse and Geisser

TABLE 41

MEANS FOR NUMBER OF MOVEMENTS, NUMBER OF RECALLS AND TYPE OF INPUT FOR ABSOLUTE, CONSTANT AND VARIABLE ERROR

	Input	Recall Sequence	Movements		
			2	4	8
absolute error	self controlled	first	7.1	9.1	19.1
		second	7.3	9.4	19.7
		third	7.5	10.9	20.2
		fourth	8.2	10.4	20.1
	experimenter controlled	first	8.4	11.7	29.1
		second	9.1	14.4	32.7
		third	10.1	15.5	30.4
		fourth	9.2	14.5	31.3
constant error	self controlled	first	-1.4	-2.5	-10.4
		second	-0.7	-1.6	-9.9
		third	-0.8	-2.1	-10.4
		fourth	-0.5	-2.9	-9.4
	experimenter controlled	first	0.1	-1.5	-19.1
		second	1.9	-3.9	-21.9
		third	2.9	-4.0	-21.0
		fourth	2.5	-2.3	-20.0
variable error	self controlled	first	4.0	8.0	13.0
		second	5.0	6.0	13.0
		third	6.0	11.0	12.0
		fourth	6.0	8.0	13.0
	experimenter controlled	first	8.0	8.0	20.0
		second	7.0	10.0	18.0
		third	7.0	14.0	17.0
		fourth	7.0	10.0	17.0

TABLE 42

ANALYSIS OF VARIANCE FOR SIMPLE MAIN EFFECTS
ABSOLUTE ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	76616	2	38308.0	351.40**
M at I_f	20308	2	10154.0	93.16**
M at I_v	61981	2	30990.5	284.31**
Input (I)	11487	1	11487.0	106.36**
I at M_2	361	1	361.0	3.31
I at M_4	2032	1	2032.0	18.64**
I at M_8	14765	1	14765.0	135.46**
M x I	5673	2	2836.5	26.02**
Pooled Error	152639	1401	109.0	

TABLE 43

ANALYSIS OF VARIANCE FOR SIMPLE MAIN EFFECTS
CONSTANT ERROR

Source	Sum of Squares	df	Mean Squares	F
Movements (M)	6686	2	3343.0	221.39**
M at I_f	1162	2	581.0	38.47**
M at I_v	6633	2	3316.0	219.60**
Input (I)	284	1	284.0	18.81**
I at M_2	85	1	85.0	5.63*
I at M_4	4	1	4.0	.27
I at M_8	1311	1	1311.0	86.82**
M x I	1113	2	566.3	37.50**
Pooled Error	21167	1401	15.1	

** significant at the 0.01 level
* significant at the 0.05 level

TABLE 44

NEWMAN-KEULS TESTS APPLIED TO DIFFERENCES BETWEEN K=3 MEANS FOR NUMBER OF MOVEMENTS

ABSOLUTE ERROR

Movements (self-controlled)

	2	4	8	Shortest Significant Ranges (.01)
Means	7.9	12.1	18.3	
7.9		4.2	10.4**	W_2= 5.2
12.7			6.2**	W_3= 6.2

Movements (experimenter-controlled)

	2	4	8	Shortest Significant Ranges (.01)
Means	9.0	14.8	33.0	
9.0		5.8**	24.0**	W_2= 5.2
14.8			18.2**	W_3= 6.2

CONSTANT ERROR

Movements (self-controlled)

	8	4	2	Shortest Significant Ranges (.01)
Means	-8.5	-3.9	-.7	
-8.5		4.6**	7.7**	W_2= 2.2
-3.9			3.2**	W_3= 2.5

Movements (experimenter-controlled)

	8	4	2	Shortest Significant Ranges (.01)
Means	-23.3	-1.8	2.9	
-23.3		21.5**	26.2**	W_2= 2.2
4.8			4.7**	W_3= 2.5

** significant at the 0.01 level

TABLE 44 (cont'd)

VARIABLE ERROR

	Movements (self-controlled)			
	2	8	4	Shortest Significant Ranges (.01)
Means	5.3	8.3	2.7	
5.3		3.0**	7.4**	W_2= .4
8.3			4.4**	W_3= .5

	Movements (experimenter-controlled)			
	2	4	8	Shortest Significant Ranges (.01)
Means	7.3	10.5	18.0	
7.3		3.2**	10.7**	W_2= .4
10.5			7.5**	W_3= 1.5

** significant at the 0.01 level

APPENDIX F

TABLE 45

CALIBRATION SCORES FOR ALL SUBJECTS OVER ALL EXPERIMENTS

	Experiments				
	1	2	3	4	5
Subjects					
1	144	142	143	139	143
2	120	136	142	143	142
3	142	143	143	144	142
4	144	142	142	142	139
5	142	142	142	143	141
6	141	142	142	143	142
7	143	141	142	142	144
8	135	140	142	142	143
9	143	142	144	143	143
10	141	143	142	143	141
11	141	141	142	143	142
12	142	140	144	140	139

TABLE 46

TWO WAY ANALYSIS OF VARIANCE
CALIBRATION

Source	Sum of Squares	df	Mean Squares	F
Subjects (S)	178	11	16.2	1.61
Experiments (E)	48	4	11.9	1.19
Error	442	44		

* significant at the 0.05 level