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By

Ross L. aurence Pepper

Dissertation Committee:

Louis M. Herman, Chairman
Hilde Groth
Samuel I. Shapiro
Herbert B. Weaver
Ian E. Reid

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Five experiments were conducted to determine the characteristics of motor short-term memory. The motor task used in all studies was the application of an isometric force to a control knob in either the upward or the downward direction, though with no actual movement of the control knob. Retention of the applied force was studied as a function of time and of other activities. Experiment I indicated that forgetting did not increase with time, for retention intervals of up to 60 sec. Experiment II found significant <u>improvements</u> in recall, and confirmed the previous observation of Experiment I of an overshooting response set during the recall trials. Experiment II also demonstrated a generally-increased decrement in recall when the retention interval was filled with backwards-counting as opposed to unfilled intervals, which suggested the importance of generalized muscle-tension states in motor memory. Experiment III compared the relative effectiveness of an interpolated counting task with an interpolated force-application task in generating interference using a standard RI design. Interference was noted in the form of a directional biasing. Smaller interpolated forces produced smaller errors than did larger interpolated forces. The results of Experiment IV provided further support for the directional-biasing mechanism, using a PI design. Experiment V investigated the effects of repetition on the forgetting function. The results indicated that with more repetition, performance at recall deteriorates. A consideration of the overshooting response set associated with the force task, in conjunction with a fading trace theory of memory reconciled the contradictory findings. Conclusions integrated the results of all five studies within a dual-factor theory of motor short-term memory. The factors were trace decay and trace interaction. Given a response set of overshooting, the type of anomalous results noted in the present paper are predictable by the two factors; given undershooting as in prior studies, typical forgetting functions are predictable.

CHAPTER I

THEORIES AND DATA OF SHORT-TERM MEMORY

Research in retention over the past ten years has been directly toward the study of short-term memory (STM). Operationally, STM may be distinguished from long-term memory (LTM) in terms of the number of times the stimulus items are presented, and the length of the recall interval employed. Most agree (Melton, 1963; Peterson, 1963) that STM is being studied when the stimulus items are presented only once and retention is measured after less than approximately thirty seconds; LTM is studied when the stimulus items are presented more than once, over a period of minutes, with retention measured after hours, days, or even weeks. There is admittedly a region somewhere between these extremes, but thus far, this region remains undefined. Definitions have been provided, however, for a sub-region of STM, often termed "very short-term memory" (Melton, 1963), investigated, for example by Sperling (1960) and Averbach and Coriell (1961), and discussed extensively in Neisser (1966) as "echoic memory". This sub-region is generally defined to include the temporal intervals from zero to approximately one second. Some investigators, however, object to this sub-region being termed "memory" since the stimulus information is conceived of as in a "peripheral" (receptor) store, rather than a "central" store. Thus, the stimulus information has not been categorized, i.e., a perceptual response has not yet occurred (Broadbent, 1963; Melton, 1963). The present paper will not be concerned with "very short-term memory," but instead will focus on findings and theories related to the previously defined broader region of STM. LTM will be discussed, but only to the degree necessary to provide a contrast with the data and theory of STM.

Theories of Forgetting

Theories of forgetting are usually of two types, based either upon (a) the assumption of autonomous decay of the memory trace over time, or (b) upon some process of interference which acts to degrade the memory trace. Recent studies of STM have reflected these two theoretical interests. One of the primary areas of controversy between these two theoretical positions concerns the necessity for making a distinction between STM and LTM. Are STM and LTM to be regarded as dichotomous, each explainable by their own laws, or are they merely points on a continuum of memory, and therefore subject to the same laws? A second related controversy focuses on the nature of forgetting itself. Is STM governed by factors of interference, factors of decay, or both? Before considering these questions, a brief review of the two major theoretical positions will be undertaken. First, the notion of trace decay will be presented, along with studies attempting to demonstrate the decay phenomenon. Second, interference theory will be presented, along with research generated within this framework. In addition, a brief review is given several studies dealing with characteristics of materials or tasks occurring before or after the learning of a primary task, for their effect on the recall of the primary task.

Decay Theory

Decay theory generally assumes that a stimulus leaves an aftereffect or trace of some sort which decays gradually unless restored by repetition of the stimulus or by rehearsal. Hebb (1949) has proposed a dual-trace basis of memory. According to this position, perception of a stimulus produces a transient reverberatory trace, or "activity" trace. Successive repetitions of the same stimulus results in a structural growth leaving a more or less permanent or "structural" trace. The fundamental premise made by the decay theorist is that the "activity" trace is subject to spontaneous decay, and forgetting is due to this progressive deterioration of the trace purely as a function of time. The probability of correct recall depends upon the extent of decay.

Once the trace has been strengthened through repetition or rehearsal, other mechanisms are brought into play to determine subsequent recall. By manipulating the rate of presentation and of recall, it is possible to control time in storage as well as to minimize rehearsal. Decay theory predicts that the amount of material retained will vary directly with the rate of presentation and recall. Using a series of digits as stimulus material, Conrad (1957), Conrad and Hille (1958), and Fraser (1958) found support for this prediction.

Another technique used to assess decay theory in STM is to vary the order of report of the stimulus material. It is assumed that the items recalled first are also recalled best, as their decay period is shortest. Thus, the total decay period of any one item is a joint function of its position in a series during presentation and its position during recall. The effects of order of report were first studied with a method developed by Broadbent (1956). Pairs of digits were presented simultaneously to both ears such that one arrived at the right ear, the other at the left ear. Reproduction by S of both digits was possible; however, for a series of digit pairs, the S generally reported all of the digits presented to one ear before those presented to the other. Broadbent (1957), Moray (1960), and Broadbent and Gregory (1961) have found that when the S was free to use any order of report, the items recalled first were recalled best. Pair by pair order of report was possible though less efficient than ear by ear recall and increased in both frequency of occurrence and accuracy as the presentation rate decreased.

A final consistent finding is that short-term storage is possible for only a limited time. Thus, Posner (1964) varied the time that an item remained in storage prior to recall and found that the longer it was stored, the greater was the probability that it would be forgotten.

Broadbent's interpretation of these types of findings is given in terms of a formal model of man as an information processing system, which STM is a major component (Broadbent, 1958). In this model, new information is lost if it is not selected for further processing from STM. An item may be retained in STM, however, by a process of recirculation from the S-system (storage) to the P-system (perceptual) and back again, representing the concept of rehearsal. When the P-system is kept occupied by other information, rapid decay of the material in the S-system occurs. Broadbent suggests that STM has a limited capacity, in terms of the number of items that may be stored at once, and in terms of the time an item may remain in storage without rehearsal, whereas LTM is not subject to such limitations.

Peterson and Peterson (1959) determined the retention of single trigrams after intervals ranging from 3 to 18 seconds. The trigram was presented auditorially in one second, a three-digit number was presented in the next second, and then to preclude rehearsal the S counted backwards by threes or fours from that number. After the appropriate retention interval had elapsed, the S was given a cue to cease counting and recall the trigram. The response measure was the percent of trigrams recalled completely correct. The results indicated a rapid deterioration in recall performance, with approximately only ten percent correct recall occurring after 18 seconds. It was deemed reasonable to assume that the interpolated task of counting backwards was unrelated to the stimulus material, so that forgetting was attributable to a rapid decay in the memory trace, rather than to any process of interference with the trace. A recent analysis of the counting backwards task in the Peterson and Peterson situation by Talland (1967), however, concluded that an important effect of the interpolated activity was its ability to disrupt the original memory-task set or orientation.

Interference Theory

Interference theory states that forgetting is the result of conflicting associations learned either prior to or after the presentation of the stimulus item. Thus the combined effects of retroactive interference (RI), working backwards on the stimulus, or proactive interference (PI), working forward in time to accelerate forgetting is offered to account for retention decrements. Termed the 'unlearning' or 'extinction' hypothesis, which suggest that previously extinguished responses spontaneously recover during the retention interval and compete with, as well as cause unlearning to take place in the previously learned responses, this position assumes an active interaction to occur among stored memory traces. This is contrasted with the independence hypothesis which assumed no such trace interaction. Recent evidence has supported the former, but not the latter of these two positions (Barnes and Underwood, 1959).

Adams (1967) suggested two hypotheses which attempt to account for forgetting as a function of competition at recall. First, the erosion hypothesis assumes that the trace is intrinsically eroded, due to the action of interfering responses within the individual's response system, rather than to the action of time alone, as in trace-decay theory. The distinction between the trace-decay position and the erosion hypothesis is that the erosion hypothesis predicts forgetting to occur as a function of the amount and type of interfering events whereas the trace-decay position assumes forgetting to occur autonomously with time. The second hypothesis suggested by Adams is based on the concept of response inhibition. It assumes that the trace remains intact, but interference produces a barrier which prevents the stored trace from being activated by the stimulus and thereby preventing the response from occurring. This differs from the erosion hypothesis in that traces are considered permanent and intact, but not retrievable, due to the interfering events involved. Thus for interference theory generally, it is the similarity of the interfering events to the original event, which is of theoretical interest.

Proactive and retroactive interference effects have been consistently reported in studies of LTM, with greater similarity between the original and the interpolated task generating greater interference (McGeoch and Irion, 1953; Osgood, 1953). Osgood's transfer and retroaction surface suggests specific predictions about the nature of the interference and transfer effects depending upon the stimulus and response similarity. The definition of similarity, however, has not been made explicit. Similarity in terms of stimulus-component overlap (formal similarity), as well as semantic similarity have both been reported effective in generating interference effects in

LTM research (Underwood and Richardson, 1956). However, Baddeley (1966) and Baddeley and Dale (1966) found that semantic similarity created interference primarily in LTM while acoustic similarity operates as a primary source of interference in STM. They suggest that practice has the effect of shifting the law of interference from acoustic dimensions to semantic dimensions. However Henley, Noyes, and Deese (1968) found that STM was sensitive to semantic structure. More interference occurred with greater semantic structure in the stimulus item. Bruning and Shappe (1965) noted that the similarity of items in an interpolated task in their experiment had an effect on recall at the longest retention intervals (16 seconds) but not at the shorter intervals.

Keppel and Underwood (1962) replicated the Petersons' study mentioned previously, and included provisions for testing the effect of multiple trials given to individual Ss. The substance of the Keppel-Underwood argument was that in the original study of the Petersons, an opportunity for proactive interference had existed over successive trials, and that this opportunity was the primary basis for the reported decrement in recall performance. Keppel and Underwood indeed did verify that performance declined significantly over test trials, regardless of the length of the interpolated interval. Their finding that test-one recall for the three-second interval was equivalent to test-one for the 18-second interval was strong evidence against a decay interpretation for the prior results of Peterson and Peterson. While the Keppel-Underwood study demonstrated progressive decrements over recall tests, this effect of prior testing was considered to be due to the development of proactive interference but unrelated to any dimension of similarity traditionally associated with proactive interference. Peterson and Gentile (1965) have found a significant reduction in the effects of the previous tests when the inter-trial interval was lengthened from 5 to 16 seconds. Peterson (1965) reported that the Keppel and Underwood (1962) study used a 10-second interval and concluded that this was responsible for much of the reported decrement.

Keppel (1968) pointed out that the multiple-testing situation of the typical STM experiment is too complex for a test between decay and interference theory. He proposed that the most profitable course would be to design future research so as to obtain forgetting under conditions of minimal interitem PI, or on the first testing after stimulus presentation. It is recognized that the forgetting reported by Keppel and Underwood poses a problem for interference theory as well, as it becomes necessary to specify the sources of interference accounting for the initially obtained decrement. "Future research must attempt to identify these sources, if interference theory is to have explanatory power" (Keppel, 1968, p. 193).

Wickens, Born, and Allen (1963) investigated PI as a function of the similarity of the prior items to the test item. They presented items of either the same class or of a different class, using as classes consonants or numbers. When the same class of items was used for both PI and test item, marked interference was found with as few as three prior items. There was no evidence that formal similarity (i.e., intra-trigram overlap) produced greater interference. A later study of formal similarity has been reported by Wright (1967). He found that increasing the length of the retention interval reduced the recall of the stimulus item and increased the recall latency as well. Increasing the similarity of prior test items reduced the correct recall score, and prior-item intrusions increased as a function of interitem similarity, but was unrelated to length of the retention interval. Wright concluded that iteritem similarity was detrimental to the storage of a later item through a process of interitem associative interference. Furthermore, increasing the length of the retention interval provided increasing time for forgetting via a memory trace decay.

Conrad (1962) reported that many auditory confusions occur in STM. Specifically letters whose pronunciation end with an ē sound (B,C,P,T,V) tend to be confused with each other in recall, and letters whose pronunciation begins with an ê sound (F,M,N,S,X) tend to be confused with each other. This confusion occurred even though the letters were presented visually for very brief periods. Wickelgren (1965) noted that the acoustic confusions could be considered as indicating a similarity dimension and set out to systematically manipulate this dimension in a STM study. If it could be demonstrated that the acoustic similarity of the interpolated items to the stimulus item affected subsequent recall, this would be strong evidence for the generality of the principle of retroactive interference, thus supporting the proposition that STM and LTM belong to the same system. Using the technique developed by Peterson and Peterson (1959), Wickelgren presented four consonants with identical acoustic properties and interpolated eight-letter lists composed of different combinations of letters which were either identical to the stimulus letters acoustically, or different from the stimulus letters. He interpreted his results as indicating that RI varied as a function of the acoustic similarity of the interpolated material. However, Conrad (1964) had suggested that another interpretation of acoustic confusions is predicted by decay theory. He states that the changing nature of the memory trace is such that errors which occur over time will be systematically related to the original trace. He further suggested that these error data are evidence against an interference position which predicts an increase in specific interitem intrusions over time. Interference theorists, however, are unwilling to accept an analysis of intrusion errors as crucial to either of the two theories. Generally, the interpretation of intrusions is an ambiguous task, as the occurrence of errors is not necessarily associated with the process of interference. Indeed, in LTM studies, overt errors are more often than not uncorrelated with interference (Keppel, 1968). Conrad (1962) has elsewhere suggested that intrusions may result from, not be the cause of forgetting.

While the argument presented by Wickelgren (1965), in terms of RI as a function of acoustic similarity of the stimulus task and the interpolated task was a strong one to interference theorists, it was open to other interpretations by the decay theorists. Conrad (1967) suggested that the reduced discriminability on acoustic dimensions over time is predictable from a modified trace decay model, and further supported by error distribution data. Wickelgren (1966) suggested that a demonstration of acoustic interference using a proactive design would be more difficult for decay theorists to deny. Thus, he had _S_s copy a list of PI letters, then copy a single letter to be recalled later, then copy RI letters until instructed to recall the single letter. The independent variables were the length of the PI and RI letter series and the acoustic similarity of the PI and RI letters to the letter to be recalled. Each _S_ was tested over 128 trials. The results indicated that significant PI and RI was developed as indicated by performance decrements for the high as compared with the low similarity conditions. It should be noted that large amounts of general PI were also involved within this design as a function of successive trials, so that a clear-cut specification of the effects is not entirely possible. However, these data weigh against the decay position in terms of the effects on the memory trace. Later versions of decay theory can handle such demonstration however, without too much alarm, in terms of competition at recall or trace differentiation (Conrad, 1967). Wickelgren is brought to the conclusion that due to the differences in the relation between length and amount of interference for the PI and RI, a two-factory theory becomes necessary. This theory includes (a) decay (or possibly storage interference--they are indistinguishable) and (b) associative interference. Specifically, Wickelgren viewed decay as a reduction over time in the strength of the association between the internal representative of the cue (phonemic similarity in the acoustic studies) and the internal representative of the correct letter. The associative interference factor refers to the competing associations established between the cue representative and representatives in nearby letters of the PI and RI lists. Thus, the correct letter will be recalled when the association from the cue representative to the correct letter is stronger than other associations. The more PI or RI letters, the greater will be the probability that one of the interfering items will have the greater strength of association, and the more RI items, the greater time the correct association will have to decay. The fact that RI produces greater effects than PI is thus accommodated by this theory. While such is the usual findings in studies of STM, it is opposite to that which is characteristically found in studies of LTM. Wickelgren's two-factor theory is a recent contender in verbal STM and appears to account for much seemingly conflicting data.

Characteristics of the Interpolated Material

In an investigation of the effects of the individual's involvement in the interpolated task Bruning, Schappe, and

O'malley (1966) tested the hypothesis that as the S became more familiar with the interpolated task, differences in recall created by active and passive participation on the interpolated task would be reduced. A multiplication task, given with or without answers (passive and active) was interpolated between the learning and recall of a paired associate task. Active multiplication resulted in poorer performance even after many trials of familiarization. Posner and Rossman (1965) varied the difficulty of the information-processing tasks interpolated between the stimulus presentation and recall test. Large decrements in their verbal task was demonstrated as a function of the difficulty of the interpolated tasks. "The similarity of interpolated materials alone cannot account for the effectiveness of interpolated items in reducing recall, since varying the difficulty is also involved" (Posner and Rossman, 1965). The authors interpret the results as support for Broadbent's (1958) model of man as a limited capacity information-processing system.

Posner and Konick (1966a) conducted a study to differentiate between a Trace-Comparison view of forgetting, which holds that forgetting is determined by the relative strength of the stored item compared to similar items during recall, and an Acid-Bath view (acid refers to the number of items in store while the concentration of the acid refers to the similarity of the stored items to each other), which assumes that interfering items spontaneously interact with the stored trace during the retention interval and thus weaken it. The Trace

Comparison view is associated with both decay theory and one type of interference theory which assumes trace independence. Thus, the problem of retrieval is basic in the Trace-Comparison position. The Acid-Bath view is based upon both decay and interference, and predicts an interaction between the difficulty of interpolated tasks and the degree of interference, which is not predicted by the Trace-Comparison view. Thus, Acid-Bath assumes an interaction of traces during the retention interval, and the Trace-Comparison view does not. Using items of either high or low acoustic similarity, the authors interpolated tasks of various difficulty levels between retention and subsequent recall. Retention ranged from 0-20 seconds. The results indicated that both the time interval that items are in store, as well as the similarity of the items affect the rate of decay. Interference was seen to be a function of both the number and similarity of the items. Posner and Konick concluded that the processes in STM involve both decay and interference, a two-factor model, to account for these and other data (Posner and Rossman, 1965).

While proponents of a single process memory take heart at the fact that interference effects have been generated in STM, by Conrad and Wickelgren, thereby demonstrating the generality of the laws of interference, these same data also demonstrate that the STM system seems to be an auditory system different from LTM with a different type of interference involved. Subsequent research by Baddley (1966) has demonstrated that acoustic similarity applies only to STM, and as previously mentioned above, Baddley and Dale (1966) concluded that semantic similarity applied only to LTM.

Adams (1967) sums up arguments for considering verbal STM and LTM as different memory systems as coming from (a) physiological studies showing defects in short-term retention which can be induced without affecting long-term retention, (b) the different type of interference to which each system is susceptible and, (c) the different storage capacities of the two systems. With respect to a, Milner (1959) found that hippocampal removal was associated with deficiencies in the transition of stored material from STM to LTM. In a recent discussion (Kimble, 1967), Milner indicated further that medial temporal-lobe lesions interfere with the consolidation process such that simple association tasks can be repeated over and over again without the patient evidencing improvement. In the same discussion, McGaugh reported that rats trained on visual-discrimination tasks and given electroconvulsive shock to the skull immediately thereafter performed randomly on a retest. Wyer's (unpublished) study, reported by McGaugh used a shock to the caudate nucleus which did not convulse the S and found essentially the same result. The shock or interfering event had to occur within 20 seconds of the learning task. Pribram (1967) concludes that neurobehavioral evidence indicates that STM and LTM refer to two different mechanisms in the brain. Evidence for (b), that interference in STM is primarily based upon the acoustic similarity of the materials while in LTM it is based upon semantic similarity has been previously reviewed, as has evidence for _c_, showing that capacity is very limited in STM and relatively unlimited in LTM.

CHAPTER II

REVIEW OF MOTOR SHORT-TERM MEMORY

Not all tasks in STM have been completely verbal. The demonstration by Conrad (1964) of acoustic intrusion errors in written recall suggests that such items involve an auditory storage or coding process. Glanzer and Clark (1963) have shown that the retention of visual nonsense patterns was directly related to the length of the verbalization which the S used to describe them. In a detailed analysis of acoustic confusion errors, Hintzman (1967) found the locus of voicing and articulation to be significant variables. His interpretation of the data was that the proximity of the kinesthetic movements in the speaking apparatus produced interference at recall. Hintzman's results did not support the hypothesis of an auditory storage mechanism mediating recall. He argued that a more plausible explanation would be interference mediated by kinesthetic cues resulting from subvocal rehearsal. He further suggested that the number of articulary cues may be the determiner of memory span, rather than the number of verbal items.

The following studies deal more directly with characteristics of motor STM and form the basis for some of the experiments to be reported in the present paper. As such, these studies will be reported in greater detail.

Adams and Dijkstra (1966) attempted to determine whether motor behavior and verbal behavior follow the same laws. In particular, does STM in motor tasks assume the same characteristics as in verbal tasks? It is well known from long-term motor retention studies that well-practiced, continuous motor responses are retained at very high levels of performance (Adams, 1964). This may be a characteristic difference between verbal LTM and motor LTM as large amounts of forgetting is generally the rule for verbal tasks. Another question of concern to Adams and Dijkstra was the variable of practice. Hellyer (1962) had previously demonstrated for verbal units that repetition of the verbal item decreased forgetting in STM, but it was not known whether this characteristic would be observed for motor STM.

Using a simple linear slide, Adams and Dijkstra required their Ss to make a blind, horizontal positioning response. The S gripped a 'car' located on a track, and on a signal from E, moved the car along the track until it intercepted a mechanical stop controlled by E. A curtain masked most of the visual cues associated with the movement. After the criterion movement was completed, the S returned the car to the start position and the retention interval began. The S waited quietly with his hand on the slide. Upon the recall command, the S attempted to reproduce (recall) the criterion movement, but with the mechanical stop removed by E. The dependent variable was the deviation in millimeters of the recall movement from the criterion movement. The retention intervals studied ranged from 5-120 seconds, with independent groups of Ss having either 1, 3, or 6 repetitions at each of several movement lengths for Experiment I and 1, 6, or 15 repetitions for Experiment II. Results from Experiment I showed that recall error increased with increases in the retention interval. The algebraic errors became increasingly negative (undershooting) over the retention intervals, but the effect of repetition was to reduce the undershoot and the variance of the error scores. The main effect of repetition, however, was not statistically significant, so Experiment II was carried out. All procedures were identical except for the change in the repetition levels noted above, and the addition of a larger S sample. The results of Experiment II indicated that repetition was a significant factor in reducing the recall error. Algebraic error diminished with increasing repetitions. Thus Adams and Dijkstra concluded that motor STM operates in a similar manner to verbal STM in terms of the repetition variable, although it required a large number of Ss (105) to demonstrate the effect. The authors further point out that it would be difficult to attribute the observed forgetting as a function of time to an interference position, as the opportunity for proactive interference prior to the criterion movement, or retroactive interference created by the S sitting quietly during the retention interval would appear negligible. Verbal coding was dismissed as well, as Ss had ample opportunity to rehearse a verbal code during the retention interval, yet forgetting occurred. Adams and Dijkstra interpreted the observed forgetting as support for the hypothesis of a decaying memory trace which becomes increasingly stable with repetition.

Adams (1967) cited the above study as providing support for the proposition that motor STM information is not stored in the form of verbal codes, and thus is not subject to the interference effects normally observed in verbal STM. Broadbent (1958) had earlier suggested that, "...phenomena which depend upon the storing of part of the information in the short-term store should therefore be less marked in bodily skills: that is, forgetting should be slower, and retroactive inhibition less" (p. 241). Broadbent went on to suggest the difference between bodily skills and verbal skills, and pointed to the possibility of two different mechanisms for handling information. His model views rehearsal as a recycling process in which information is passed from short-term storage to a perceptual system and back again to storage. Therefore, rehearsal of nonverbal material would be meaningful to consider as an interfering task only if it could be shown to require a portion of the information-processing capacity (perceptual system) of the individual.

In a study of verbal STM, Crowder (1967) interpolated a key-pressing task between the presentation and recall of the verbal stimulus item. The interpolated motor task was self-paced, and varied on the dimensions of stimulus-response compatibility and coherence (predictability). A five-word stimulus was presented and tested for recall after 24 seconds. Evidence for some rehearsal occurring during the experimental trials was indicated by improved performance on the key-pressing task when no stimulus words were presented (control trials). In addition, it was found that as the interpolated motor task increased in coherence, recall was better, and when the motor task components were more compatible, recall was also facilitated. Thus, Crowder suggested that his results support a single-channel, information-processing mechanism as basic to both verbal and nonverbal memory processes.

Posner and Konick (1966b) presented a series of studies which were designed to investigate the role of central-processing capacity in the retention of information from different sensory components of motor skills. The visual-location task consisted of a small circle located at one of 12 positions along a 7 1/8 inch line. The positions ranged from 1 1/8 to 6 7/8 inches, from left to right. The S̲ was presented for one second with a page which had the circle located at one of the positions. After a retention interval of 20 seconds, the S̲ was required to mark on another page the appropriate position of the circle. The kinesthetic-distance task used an angular-positioning device modeled after one designed by Bilodeau, Sulzer, and Levy (1962). The S̲ was required to position a lever from a starting position to the 90 degree vertical position on a 180 degree scale. Starting positions ranged from 20 degrees through 160 degrees. The criterion movement was defined by a peg which limited S̲'s movement. The recall movement was carried out on another apparatus, identical to the first one, but at right angles to it and with the stop removed. The visual-location and kinesthetic-distance tasks were thought to sample different sensory parameters (visual, spatial, proprioceptive) which are of importance in motor skills. The interpolated tasks used were previously found to be ordered in terms of the number of bits of uncertainty reduced in their performance (Posner and Rossman, 1965). The results of the Posner-Konick study indicated that for visual-location, there was no forgetting when the retention interval was left unfilled. The rate of forgetting of visual-location, however, was a direct function of the amount of information-processing capacity available for rehearsal during the retention interval. These results are similar to those reported previously by Posner and Rossman (1965) using verbal units, and Crowder (1967) using verbal units with an interpolated motor task. However, forgetting of the kinesthetic-distance task was not related to the interpolated activity. Forgetting occurred in the same manner regardless of whether the S̲ rested or performed a highly demanding numerical task during the retention interval. The characteristics of forgetting associated with the kinesthetic task are thus similar to findings of Adams and Dijkstra (1966). Posner and Konick concluded that different memory codes are used for visual as compared to kinesthetic information.

Posner (1967) used the same tasks as described above for the Posner-Konick study, but in addition used a factorial design so that the effects of modality (visual and kinesthetic) and information type (location and distance) could be assessed individually. The Ss were randomly assigned to one of four groups, consisting of visual location, visual distance, kinesthetic location or kinesthetic distance. The only difference between visual and kinesthetic was whether S was permitted to view his hand during performance of the task. The difference between location and distance was that for location, the start position at recall was identical to the start position used on the criterion trial, whereas for the distance task a new start position was used. Thus for the distance group, only the actual extent of movement remained as a cue for recall. The interpolated tasks as previously described in Posner and Rossman (1965) were used to reduce the opportunity for rehearsal.

Posner reported only the absolute deviation error from the original criterion position to the recall position. All conditions except visual-location with interpolated rest showed significant forgetting over the 20-second retention interval. The visual-location task with rest (no interpolated activity during the retention interval), showed a significant decrease in error over the same 20-second interval. An analysis of variance performed on the four conditions indicated that only the modality by interpolated activity interaction was significant. This showed that the interpolated activity was effective in increasing forgetting for the visual but not for kinesthetically based tasks. Thus, Posner concluded that his data were consistent with previous findings which suggested that the storage mechanism for sensory information involves more than verbal labels, and that visual and kinesthetic tasks have different information-processing requirements. This result was also seen to be consistent with theorizing by Broadbent (1958), who suggested that the degree of awareness involved in the processing of information was directly related to the amount of channel capacity required by the task.

In the studies of Posner and his colleagues, it is evident that their research strategy has been guided by conclusions derived from Broadbent's (1958) model of man as a limited-capacity information processor. The research on motor STM has demonstrated that motor-trace retrieval is not affected by difficult, channel-loading tasks which are highly verbal in nature. However, it is still conceivable that an interpolated motor task might evidence some disruption of a criterion motor task.

Adams (1967) concluded from an analysis of his own studies, as well as other studies, that motor STM obeys different laws than verbal STM. The Adams and Dijkstra study and the Posner studies showed no effect of prior trials; therefore, the possibility for proactive interference in the forgetting of motor tasks appear remote. However, it should be noted that during the retention interval, Adams' Ss merely sat and waited passively. While Adams and Dijkstra suggest that the unfilled interval would have allowed rehearsal if the traces were verbally encoded, rehearsal per se does not guarantee correct rehearsal, so that the lack of facilitation of recall does not logically demand the type of conclusion reached by Adams.

Interference Effects

A review of previous studies in the area of motor skills indicates that the demonstration of an interference effect is not easily accomplished (Adams, 1964). Lewis (1947) reported a weak effect of RI, and only when the interpolated task was antagonistic to the criterion task. In a study designed to investigate the similarity of psychophysical judgment as compared to memory tasks, Postman and Page (1947) demonstrated that the precision of discriminatory judgment was subject to RI. Using a compromise between the method of constant stimulus differences and the method of single stimuli, Ss were required to judge the attributes of a rectangle (height or width) for a series of successive judgments, then asked to judge the opposing attribute (width or height), and finally asked again to make the first judgment. Appropriate control groups were used. The results indicated that interpolated judgments of opposing attributes resulted in greater error scores when the first judgments were again made. Postman and Page interpreted this decrement as reflecting RI from an incompatible response set developed by the interpolated judgments. In addition, the authors attributed the classical "time error" obtained in psychophysical-judgment experiments to the same RI mechanism, but in which the interfering events which interact with the trace remain unspecified. Duncan and Underwood (1953) were unsuccessful in generating proactive interference in a discrete motor task in LTM. Mandler (1954) found evidence for negative transfer of a motor task in LTM in a similar design to the conventional PI design of verbal-learning studies; however, extreme overlearning on the prior task was required in order to demonstrate the interference effect.

Blick and Bilodeau (1963) conducted two experiments to test the effects of an interpolated task on the acquisition of a simple arc-drawing task. In the first experiment, the interpolated task varied in terms of quantitative similarity (degrees of arc) to the initial task. In addition, one group performed interpolated tasks which were dissimilar (opposite in direction) to the initial task. The results were presented in terms of absolute errors and variances. No significant differences between groups were noted. The second study added a control group which sat quietly during the interpolated interval, in order to assess the effect of direction which might be contributed by the interpolated tasks. The results again indicated that the arc-drawing response was not affected by interpolated drawing tasks, regardless of the similarity between the interpolated task and the criterion task. However, accuracy and response set could not be assessed as only absolute errors were reported. The authors considered their results in terms of generalizations derived from Osgood's

(1953) transfer surface, and concluded that the failure to obtain differences was possibly due to the simple nature of their task. They also concluded that the possibility of demonstrating RI in simple, discrete motor tasks was remote.

In research in STM, Fox and Rogers (1966) reported forgetting of a simple motor response (drawing a geometric form) through the use of an incidental-intentional training procedure. This procedure includes practice of an incidental task which is then to be recalled following performance of an intentional task. Thus, _S_s were instructed to practice drawing a specified geometric form as accurately as possible. This resulted in a relatively slow, self-paced response. The _S_s were then instructed to draw the figure as rapidly as possible, which produced a rapid rate of response. During recall, _S_s were required to draw the figure at the same _rate_ as during the initial task, when accuracy had been stressed. The results indicated that groups which had the fast drawing task interpolated between the initial and recall task demonstrated poorer recall of the appropriate rate of responding than a control group which had no such interpolated practice. The authors concluded that the forgetting was due to the development of an inadequate set at recall which conflicted with the appropriate set established by the memory task.

Boswell and Bilodeau (1964) investigated the nature of task engagement as compared to task disengagement interpolated between the criterion and recall task. _S_s were required to blindly position an angular control to a stop controlled by E. Half the Ss then disengaged from the task apparatus, and left the room to retrieve a pencil, returned and then re-engaged the apparatus. After an interval of 28 seconds, the recall test was performed. The remaining half of the Ss merely returned the control to the start position, and waited quietly during the retention interval. The results indicated that disengagement created significant decrements in recall, but merely sitting did not. The data were reported in terms of absolute error scores and correlations, so that an assessment of response accuracy was not possible. The authors concluded that forgetting was due to a loss of set resulting from changes in postural and environmental cues S used to produce the criterion task.

The above studies are open to criticism in terms of design characteristics. Thus, the studies of Bilodeau and his colleagues, of Posner, and of Adams all used a criterion positioning task which was dissimilar to the subsequent *recall* task. The S was required to make the initial positioning response, which was defined by either a stop, or a peg which limited the extent of response for S. During the subsequent recall test, the peg or stop was removed, and S reproduced what he "felt" was the correct response. The kinesthetic and proprioceptive cues arising from the initial positioning and from the recall positioning are quite different. Thus, the rapid deceleration involved when the S's criterion movement was terminated by a stop was not involved in the recall movement. Also, the initial acceleration and velocity changes were uncontrolled variables which certainly contribute to motor forgetting (Bahrick, Fitts, and Schneider, 1955).

The Posner studies used interpolated tasks which were highly verbal in nature. Task _a_, Reversal, required the _S_ to write down a pair of digits in the opposite order from their presentation. Task _b_, Addition, required to _S_ to sum two adjacent digits and record the answer. Task _c_ was a classification task. The _S_ was required to classify numbers into "high" or "low" categories. In task _d_, the _S_ recorded _A_ if the number pair was high and odd, and _B_ if the reverse. These tasks were developed as intervening material in the initial short-term memory studies of Posner and his colleagues, in which the stimulus materials were letters of trigrams. The relationship between this type of verbal interpolated activity and the required motor response may not be on interference dimensions, in the sense that they would appear to be very dissimilar on Osgood's (1953) transfer and retroaction surface.

A demonstration of retroactive interference in short-term motor memory seems more probable if the proactive or retroactive material is itself motor and varies along some reasonable dimension of motor similarity. Very preliminary pilot work by the present investigator using a linear slide apparatus similar to the Adams and Dijkstra (1966) task indicates that antagonistic movements (opposite in direction) may be less interfering than similar movements (slide moved in the same direction) with the criterion movement. While scant attention can be paid this work, a personal communication from H. P. Bahrick indicated than an as yet unpublished replication and extension of the Adams and Dijkstra study has found interference effects.

The experiments to be reported in this paper are directed toward the research strategy suggested by Melton (1963): Can the general laws of interference derived from studies of verbal memory explain data generated in motor memory? It has been suggested that PI effects are primary in inducing forgetting in verbal LTM. On the other hand, in verbal STM, PI seems less dominant, reaching a maximum influence after just a few items, and certainly subordinate to the RI effects which seem to account for the greater portion of forgetting (Wickelgren, 1965). In the area of motor STM, however, only very small effects of RI have been observed, and PI has not been investigated at all.

The proposed experiments are designed to examine the characteristics of motor STM. Of interest are the time relationships of motor STM, i.e., how rapidly forgetting may occur, and whether any type of PI or RI effect may be demonstrated.

A major difference between the motor task to be used in the present experiments on motor STM and the tasks used in the studies previously cited should be noted. The past studies generally used positioning movements whose end points were defined by an artificial stop used during the criterion trial. During the recall test, this stop was not employed. This suggests that the criterion and recall movements were different, and casts some doubts on the generality of the forgetting obtained in this situation. In addition to this consideration, the movements--both criterion and recall--were of considerable magnitude and it would appear that in most studies, non-motor cues, such as the judged angle of the arm relative to the shoulder, might be available to S during recall. If this were the case, the degree to which 'motor' STM was being measured becomes subject to question.

The task to be used in the present experiments involves the application of a isometric force by S to a knob, rather than the movement of a lever or car. The force is applied to a transducer whose maximum movement is .082 mm in extent. Hence any non-motor cues associated with the production of the criterion force are eliminated. In addition, no artificial stops or limits characterize the present task, and the similarity of criterion task to recall task is thus better assured.

CHAPTER III

STUDY OF MOTOR SHORT TERM MEMORY I. EFFECTS OF AN UNFILLED INTERVAL ON RETENTION OF AN APPLIED FORCE

This first study was conducted to investigate the performance of the human subject in a more refined motor task than used by Adams and Dijkstra (1966). In particular, gross physical movements associated with the positioning cues used in prior research have been eliminated in the present case. Of major interest is the effect of the length of the retention interval following application of a criterion force upon subsequent recall of that force. The criterion force is always applied under visual control by S: recall is always made without visual control.

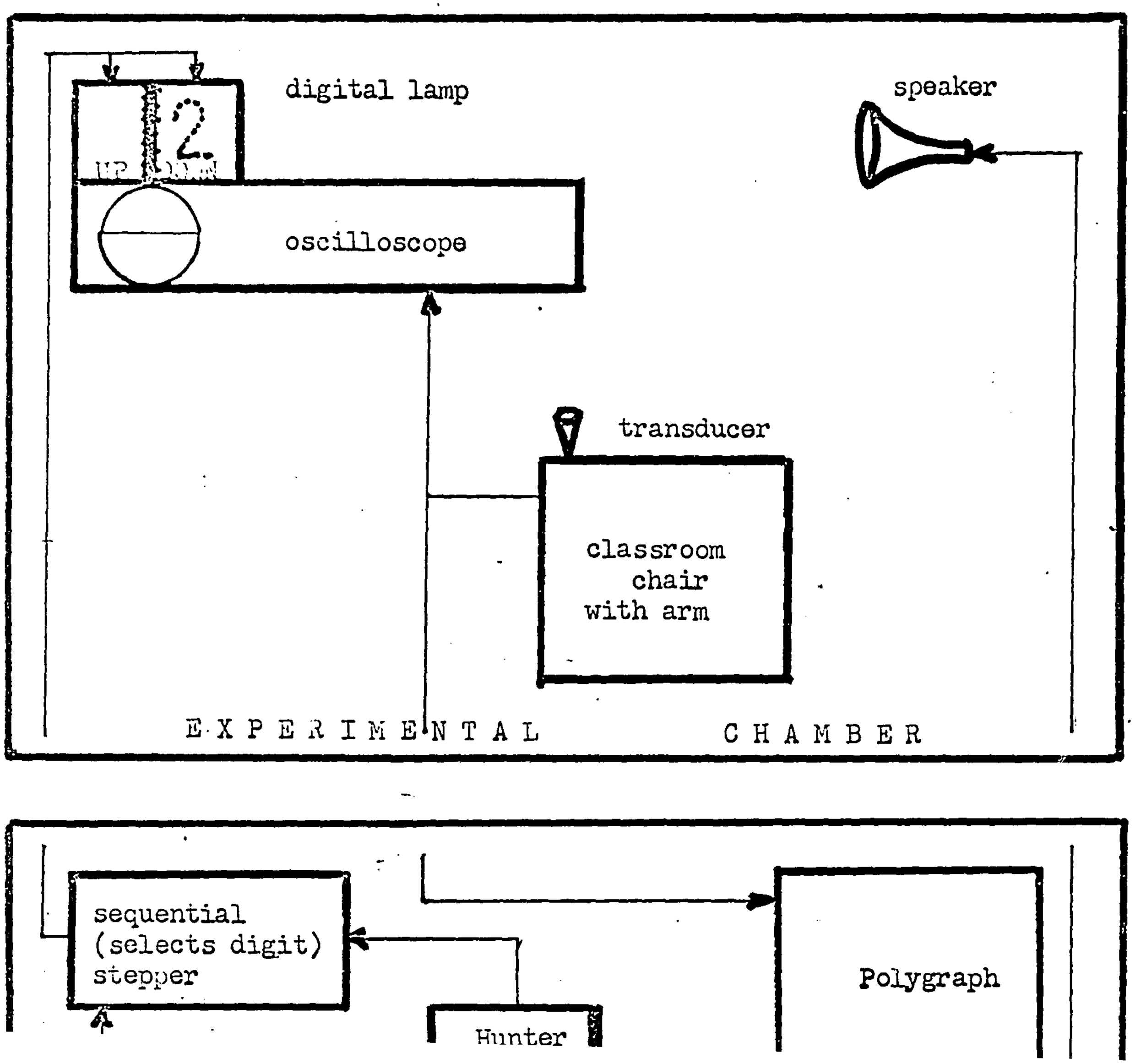
Method

Subjects

Twenty University of Hawaii undergraduate volunteers from an undergraduate pyschology class participated for course credit. A total of eight male and twelve females were used in the experiment. None had previously served in a memory experiment.

Apparatus

Figure 1 provides a block diagram of the apparatus used in the present study, and in the additional studies to be reported. The experimental chamber was electrically shielded and airconditioned and was provided with a communications


digital lamp
2
UP
DOWN
oscilloscope
speaker
transducer
classroom chair with arm
EXPERIMENTAL CHAMBER
sequential (selects digit) stepper
Hunter
Polygraph

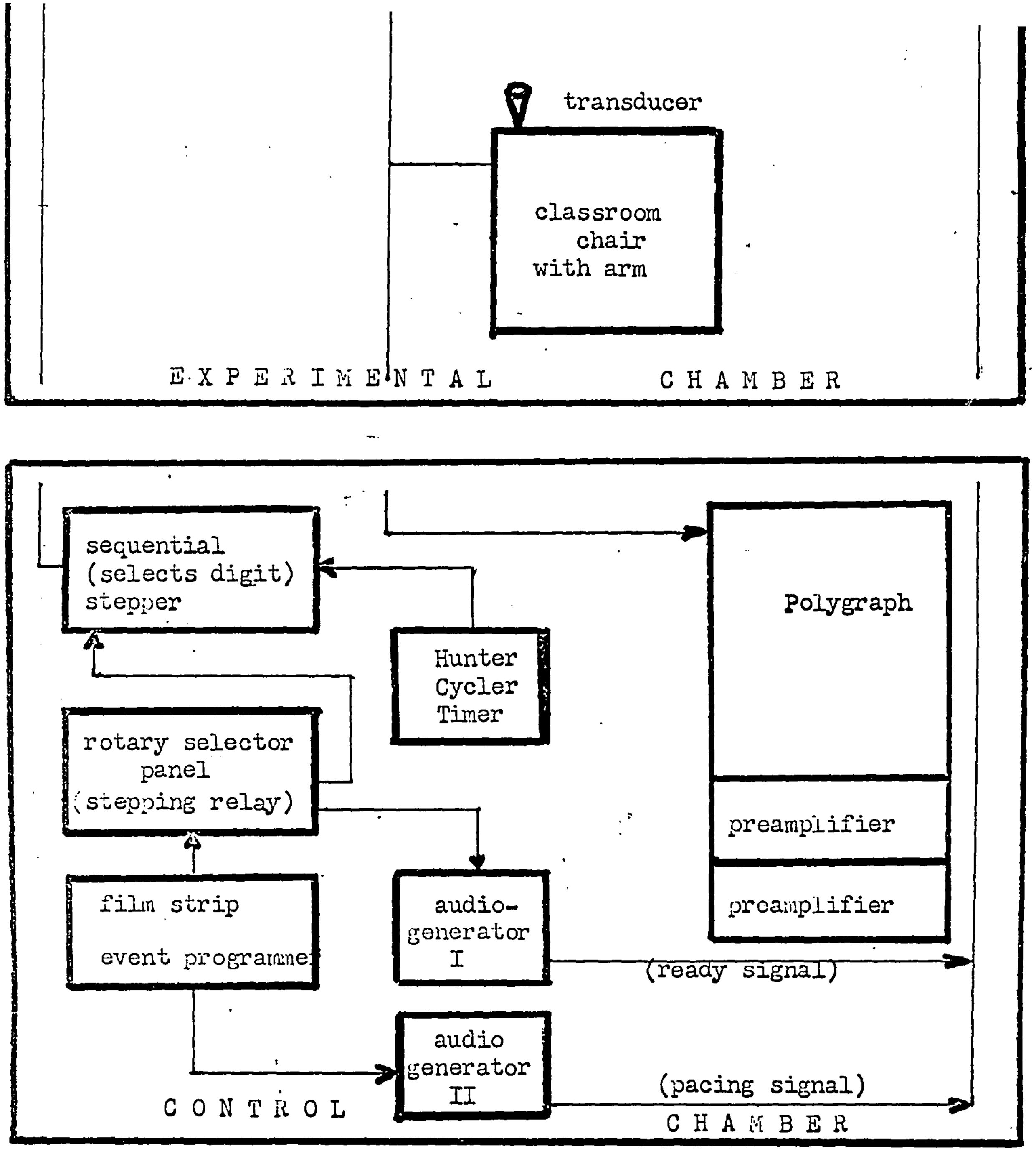


Fig. 1. Block Diagram of Apparatus Used in Experiment I

system with the adjacent control room. Mounted on the arm of a standard classroom chair located in this chamber was a force transducer, Model UC3, manufactured by Statham Instruments, capable of transmitting forces from zero to 30 grams by either a downward force (push) or an upward force (pull). A Load-Cell Assembly, Model UL20 (Statham), was fitted to the transducer to provide a transformation of the force ranges from zero to 4.85 kilograms in either the downward or the upward direction. The S applied the forces on the vertical dimension only, by a gear-shift control knob mounted on the transducer. The actual physical movement of the transduced over this force range was a maximum of .08 millimeters.

The output of the transducer was fed to a visual display positioned directly in front of Ss chair at a distance of 24 inches and at approximately eye level from the seated S. This display consisted of the transducer output signal, appropriately amplified and presented on a Hewlett-Packard oscilloscope, Model 120B. The oscilloscope was adjusted so that with zero force applied to the transducer a stationary full-width, horizontal beam rested at the centerline of the scope face. The transducer output was calibrated so that a downward force on the transducer (pushing downward on the control knob) resulted in the horizontal beam moving downward, while an upward force (pulling upward on the control knob) resulted in the beam moving upward. The face of the oscilloscope was incremented in one centimeter steps for five steps above, and five steps below the centerline. The force required to position the line at each successive step either up or down was quite linear, with a force of 850 grams required to reach the first position ("force one"), and 4.20 kilograms required to reach the fifth position ("force five").

In the adjacent control room was located a Grass six-channel polygraph, Model 5D. The output of the transducer was fed additionally into two low-level DC pre-amplifiers of this polygraph so that upward forces were recorded on one channel, and downward forces were recorded on a second channel. The use of two channels provided for maximum force resolution on the chart paper, using only the center 40 millimeters of each channel, which is rated as linear within 2%. A 40 mm pen excursion was thus a force-five response.

A two-element digital lamp was installed in the experimental chamber just above the oscilloscope. The left element was labelled PULL UP, and the right PUSH DOWN. This lamp was connected to a specially-fabricated rotary-selector switch panel and stepper located in the control room, which enabled E to present the numbers zero through five to S, in order to define the required positioning task. For example, a "1" presented in the left element of the digital lamp indicated to S to pull up on the control knob until the horizontal beam of the oscilloscope rested on the first one-centimeter increment above the centerline; a "1" presented in the right element indicated that S was to push down until the horizontal beam rested on the one-centimeter mark below the centerline. The zero was used in several studies when an interpolated task of "no response" was required. Also located in the adjacent control room was a Hunter Interval Recycling Timer, which controlled the presentation duration of a digit and the time intervals between successive digit-pairs. A Grason-Stadler stepping relay was used to control onset and offset of the horizontal beam on the oscilloscope display. A film-strip event programmer, driven by a synchronous motor, provided the input signal to the rotary-selector switch panel and performed the necessary timing function for the interpolated retention intervals. Finally, there were two Scientific-Prototype audio-generators employed. Audio-generator-1 was used to present an 800 cps 3-second tone into the experimental chamber to warn S of the start of each new trial block; audio-generator-2 presented a 1500 cps pulsed tone used in Experiments II and V to pace a counting task required of S.

Experimental Design

A 5 x 2 x 5 within-Ss design was used to test for effects of force level, direction of movement, and length of retention interval. Each S was required to respond to five 'Up' force levels and five 'Down' force levels, with each level in turn associated with five retention intervals of 4, 8, 12, 30, or 60 seconds each. Thus, each S received 50 unique trials during the course of the experiment, in five blocks of ten trials.

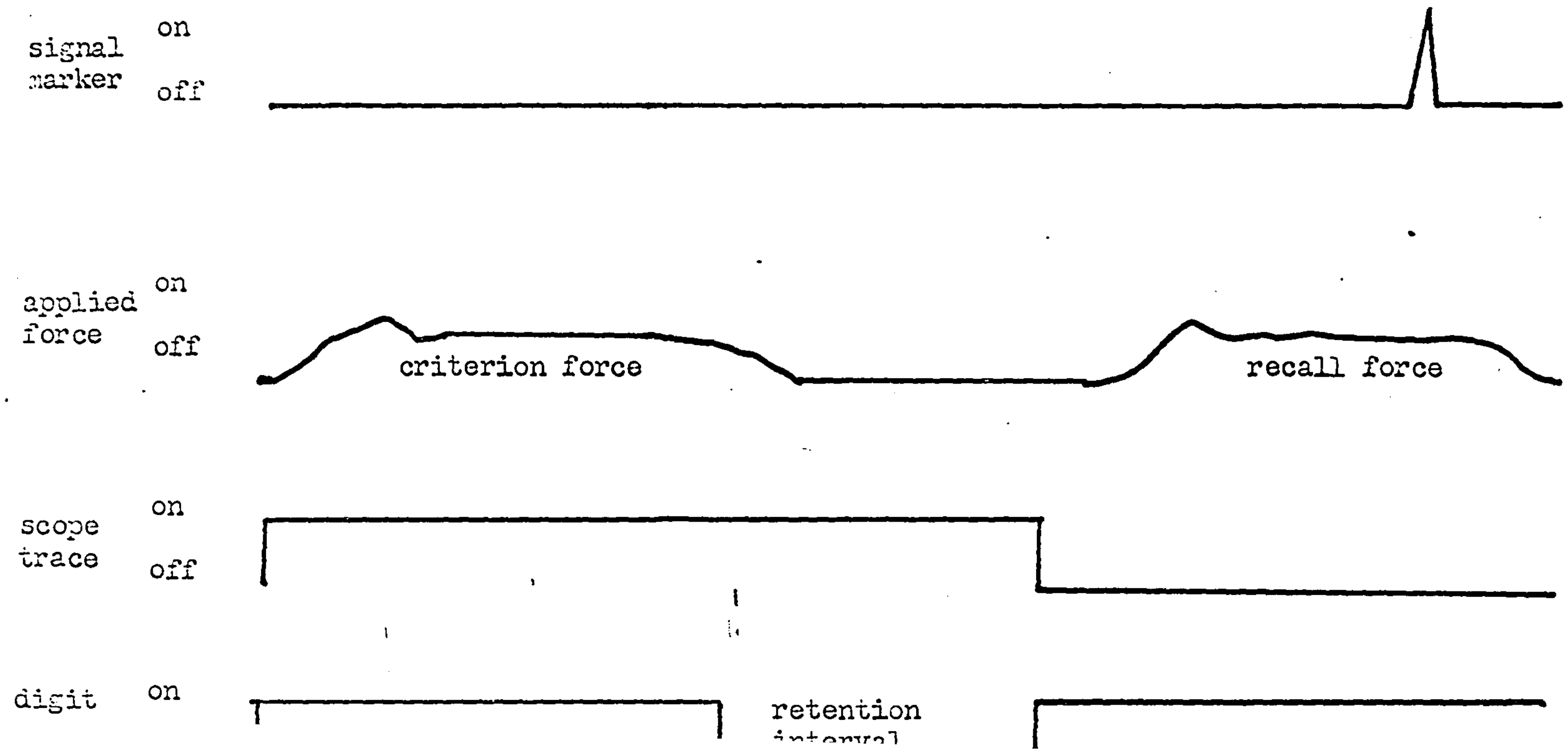
A 5 x 5 Latin square which minimized sequence effects was generated (Fisher, 1947), and 20 unique orders of five blocks were obtained by using all rows and all columns of this square. Each of the 20 Ss was then administered a different unique order of the five blocks by use of this square. Within each block of ten trials, Up and Down occurred equally often with each force and with each retention interval. Up and down alternated both within and between blocks, while a given retention interval occurred twice within a block, once with an Up and once with a Down. The same interval never followed itself, and the blocks were constructed so that both greater and lesser forces occurred equally often both at the start of a block and at the end of a block.

Procedure

The Ss were tested individually. Each S was read the Subject Instructions (Appendix 1), and run through a simulated trial, using a force level not employed in the experiment proper. Following the reading of the Subject Instructions, all communication with S was via the Intercom system from the control room.

The S sat in the chair, his right forearm resting on a foam-rubber pad attached to the arm of the chair. He gripped the control knob with the fingers and thumb of his right hand so that he was easily able to apply an upward 'pull' or a downward 'push' on the knob. A trial consisted of the successive presentation of two digits. Upon onset of the first digit, signalling the criterion force to apply, S positioned the horizontal beam of the oscilloscope appropriately, and maintained that position (force) as long as the digit remained lighted--a period of six seconds. The offset of the digit was S's signal to release his pressure on the knob, allowing the beam to return to the centerline position. Following an interpolated time interval, the same digit again occurred, only this time the horizontal beam on the oscilloscope 'disappeared'. The S now had to position the knob to what he 'felt' was the correct force, based upon his previous experience under visual feedback, of applying that particular criterion force. In order to identify the point at which S felt that he had accurately reproduced the criterion force, he was provided in his left hand with a spring-loaded switch and instructed to press it at the moment when he felt he had applied the correct force. Pressing the switch activated a signal-marker pen on the polygraph. Figure 2 shows a schematic time sequence of the events of the present experiment, showing an application of a criterion force followed by a four-second retention interval and a recall trial without visual-guidance.

The intertrial interval following the recall test was 30 seconds. Peterson and Gentile (1965) have indicated that 20 seconds is a sufficient length of time for proactive interference effects to be minimized, at least for verbal units. A three-minute rest period was given between each block of ten trials. During this time, S released his grip completely from the knob. A tone was the signal for S to reapply his grip and be ready for another block of ten trials in approximately ten seconds. Each trial block required


signal marker
on
off
applied force
on
off
criterion force
recall force
scope trace
on
off
digit
on
retention interval

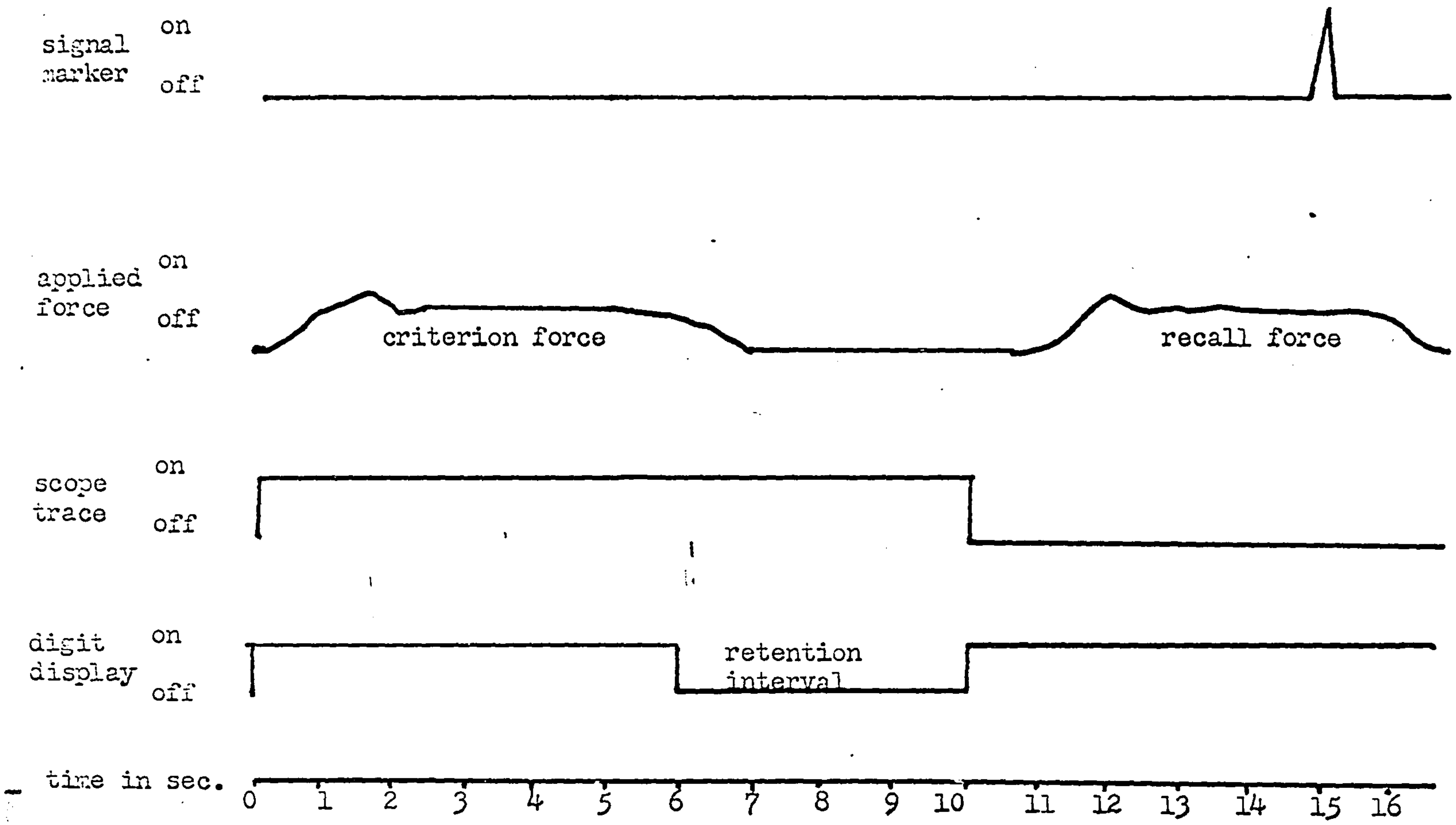


Fig. 2. Time-line of Events of Experiment I

approximately nine minutes to complete.

Results

The polygraph records for each S were scored by hand. For each trial the difference between the initial visually-guided criterion response and the recall response made without visual-guidance, was measured in millimeter units. The signal marker provided the identification of each recall response on the polygraph record. Agreement in scoring between independent raters (the writer and his assistant) on preliminary tests was 100% with this method. The data were submitted to both absolute and algebraic error analyses. Previous research (Posner and Konick, 1966b; Posner, 1967) had reported results in absolute error scores; however, Adams and Dijkstra (1966) reported both absolute and algebraic errors. Since overshooting--applying a recall force greater than the criterion force--was quite prevalent--and can only be detected by an analysis of the algebraic errors, and to obtain as comparable results as possible with prior research, both absolute and algebriac errors and their respective analyses will be reported in the present paper.

Table 1 provides a summary of the mean errors for the three variables under consideration. It can be seen that for the absoluteerrors, effects of direction of movement (Up or Down) appear to be slight, as also do effects of force levels and retention intervals. Note that the mean algebraic errors, however, are all positive and close to the value for the absolute errors, indicating the predominant tendency of

Table 1

Mean Absolute and Algebraic Errors in Millimeters For Direction of Movement, Force Level, and Retention Interval

Direction

Up	Down
4.92(4.18)	5.05(4.40)

Force

1	2	3	4	5
4.53(4.36)	5.08(4.68)	5.29(4.50)	5.14(3.93)	4.91(3.96)

Time

4	8	12	30	60
4.91(4.62)	5.00(4.48)	4.70(4.03)	5.22(4.13)	5.11(4.18)

NOTE--Algebraic Errors are in Parenthesis

most Ss to overshoot the criterion force during recall. Figure 3 shows a plot of the variable of major interest, retention intervals, and indicates the relatively rapid reduction in algebraic errors with increasing intervals.

Table 2 presents the results of a three-way analysis of variance, including trend components, carried out on both the absolute and algebraic errors. For both analyses, it can be seen that the main effect of direction of movement was not significant, nor were the main effects of Force or Retention Intervals, nor the trend components associated with these latter two variables. Thus the trend noted in Figure 2 was not significant.

The interaction of Up-Down by Force was significant for both analyses. Figures 4 and 5 show plots of this interaction for the absolute and algebraic errors respectively. It can be seen that the interaction is due primarily to a reversal in error direction for force five. The algebraic analysis also indicates a significant interaction of Retention Interval with Direction. Figure 6 presents this interaction graphically, showing that Down errors tend to be smaller at 4 and 60 seconds than Up errors, while the errors at the remaining intervals show the reverse effect.

Table 2

Absolute and Algebraic Error Analysis
For Unfilled Retention Interval Study

		Absolute			Algebraic		
Source	df	MS	F	p	MS	F	p
Ss	19	204.46					
Up-Down (A)	1	4.22	0.18		11.64	0.34	
Ss x A	19	23.39			33.97		
Force (B)	4	16.88	0.73		21.85	0.79	
Linear	1	12.98	0.56		47.64	1.73	
Quadratic	1	52.96	2.28		13.45	0.49	
Cubic	1	1.24	0.05		24.29	0.88	
Remainder	1	0.36	0.02		2.00	0.07	
Ss x B	76	23.23			27.52		
Time (C)	4	8.06	0.88		12.76	0.90	
Linear	1	7.76	0.85		31.25	2.22	
Quadratic	1	2.62	0.29		12.43	0.88	
Cubic	1	1.24	0.14		1.33	0.09	
Remainder	1	20.64	2.26		6.02	0.43	
Ss x C	76	9.13			14.10		
A x B	4	180.74	17.95	.01	107.02	7.11	.01
Ss x AB	76	10.07			15.06		
A x C	4	17.11	1.36		58.03	4.53	.01
Ss x AC	76	12.56			12.82		
B x C	16	8.83	0.98		18.14	1.35	
Ss x BC	304	9.03			13.41		
A x B x C	16	16.75	1.62		28.07	2.06	
Ss x ABC	304	10.32			13.64		

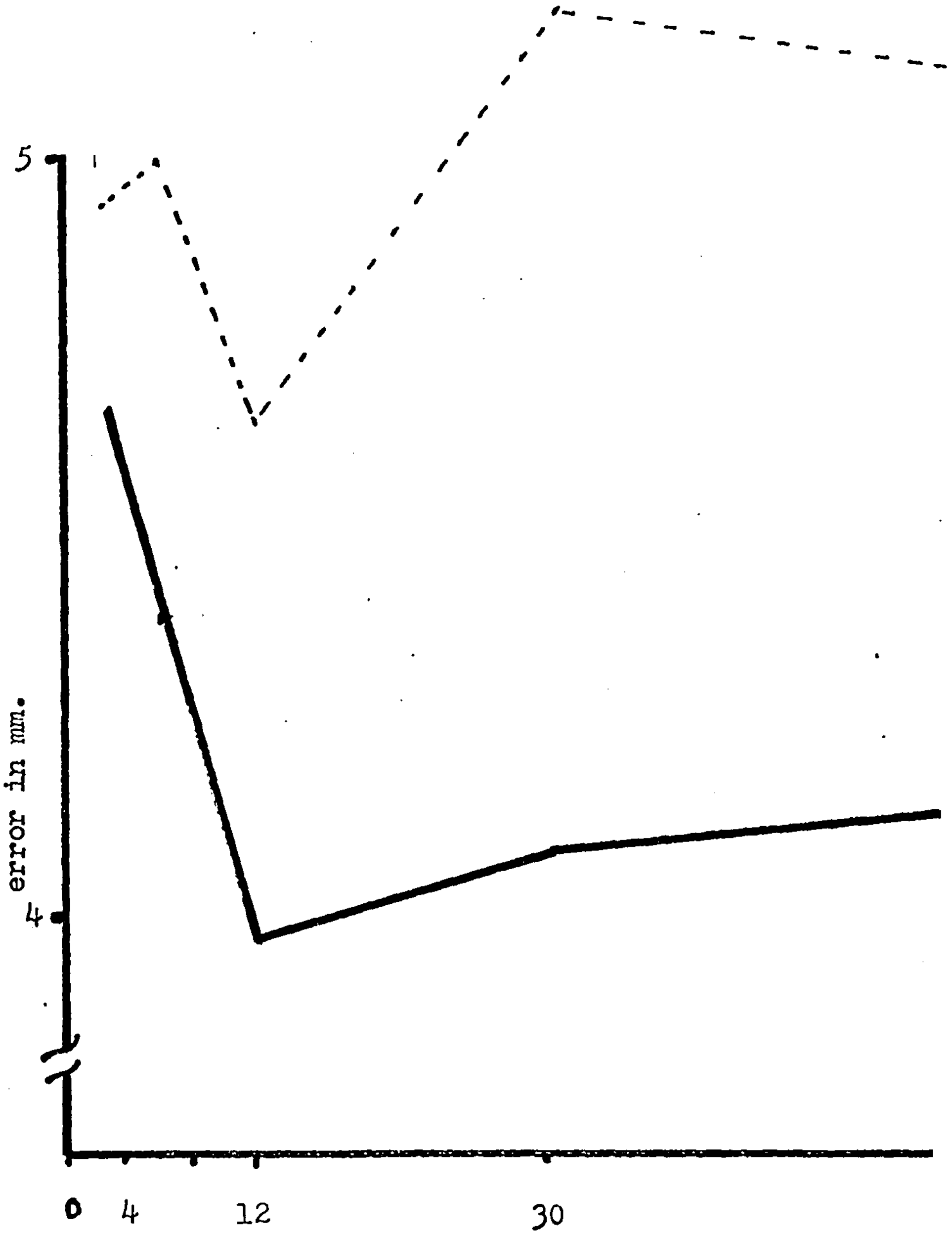
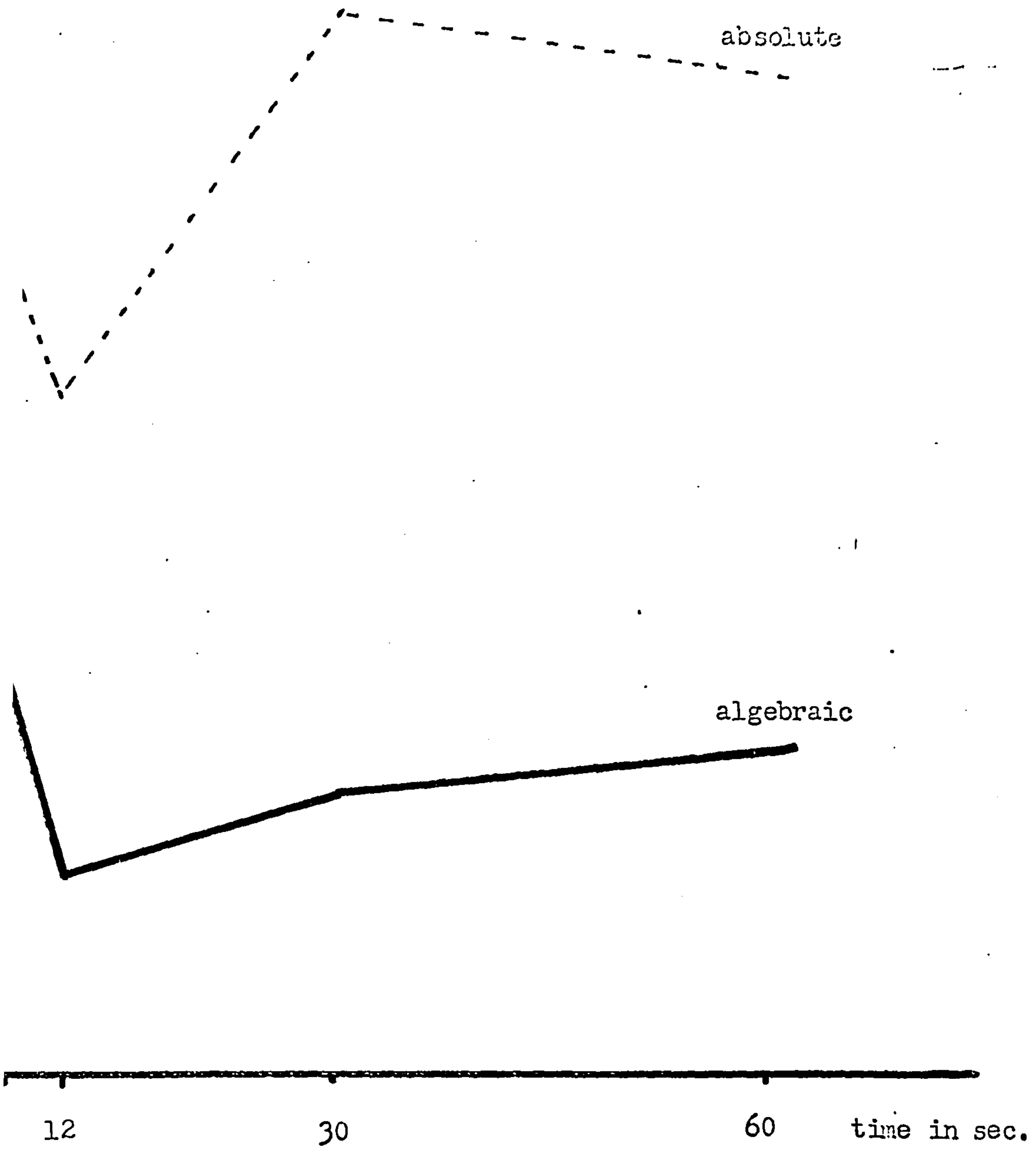


Fig. 3. Absolute and Algebraic Errors as a Function



. Absolute and Algebraic Errors as a Function of Retention Intervals in Experiment I

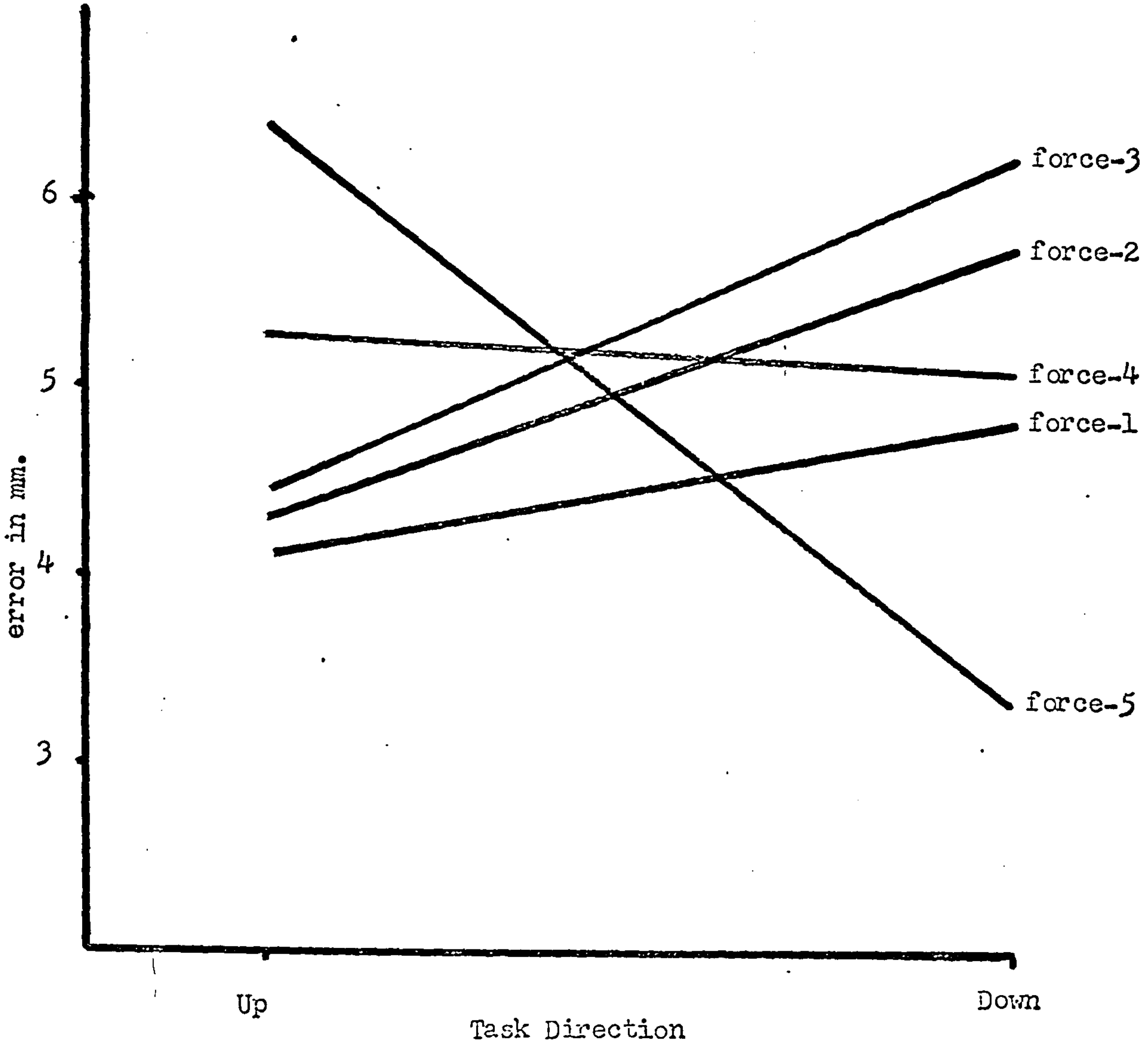


Fig. 4. Up-Down by Force Interaction with Absolute Errors

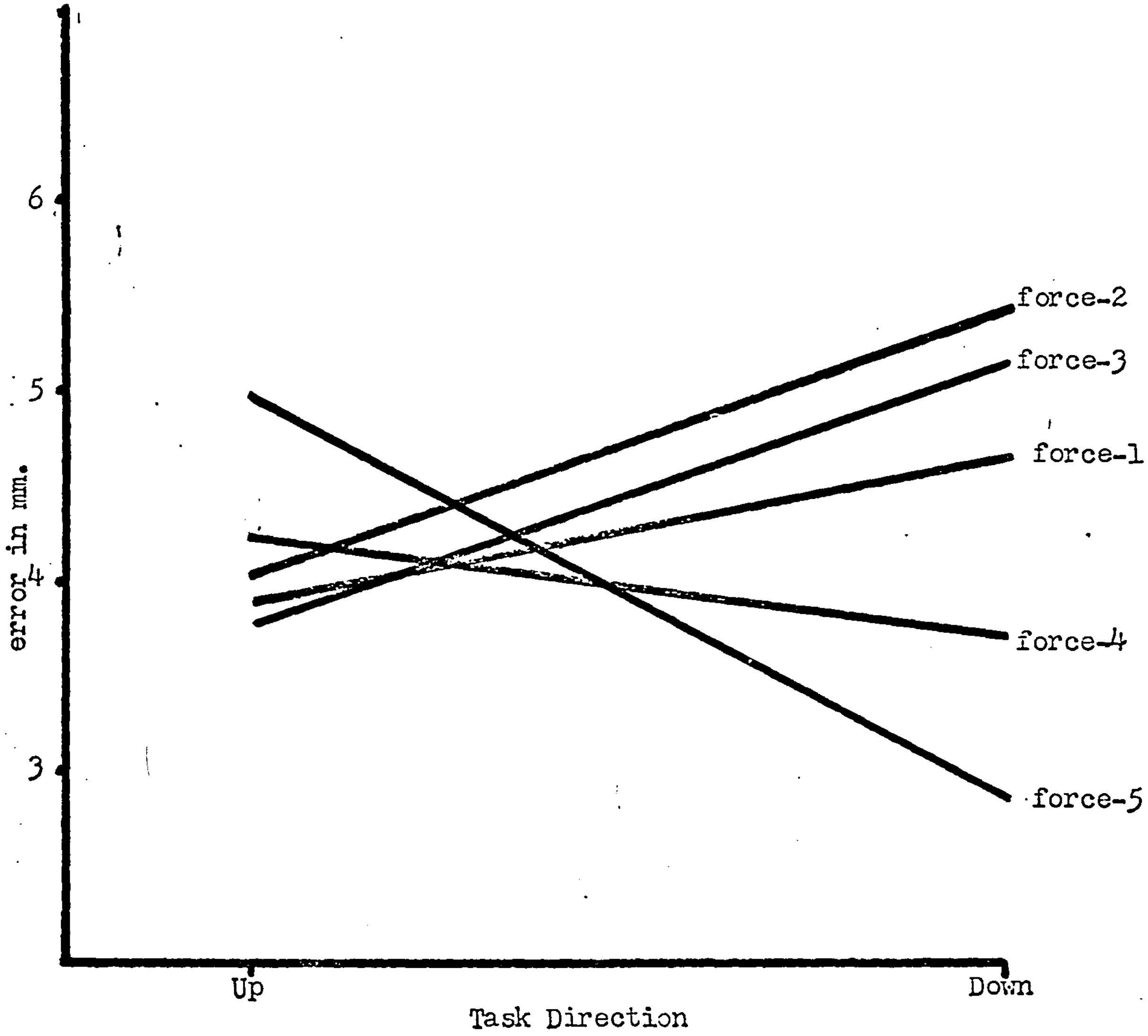


Fig. 5. Up-Down by Force Interaction with Algebraic Errors

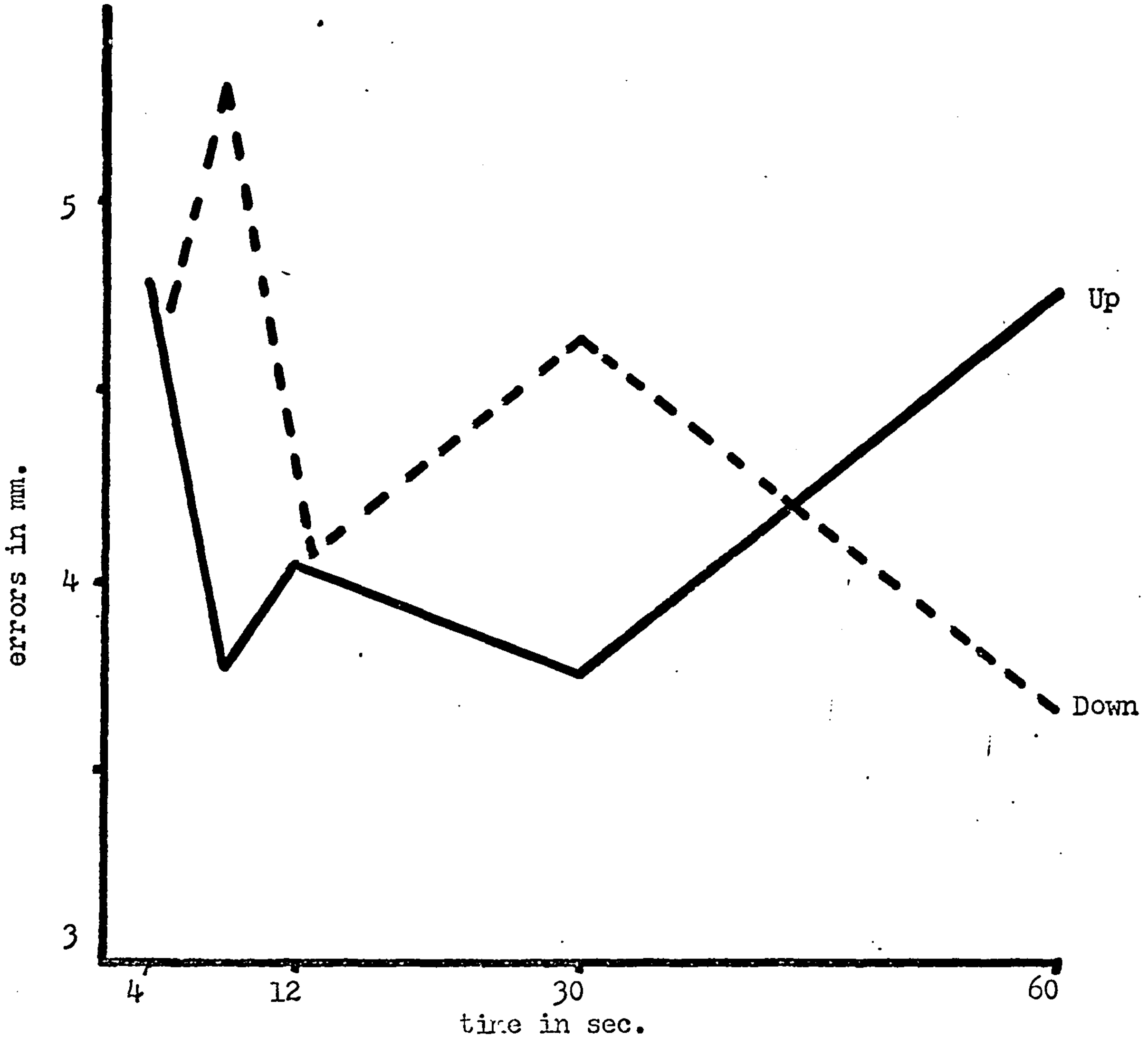


Fig. 6. Up and Down Tasks over Retention Intervals with Algebraic Errors

Discussion

The results of the present experiment did not demonstrate a significant decrement in recall over the time intervals employed. Rather, absolute error appeared unrelated to the retention intervals. This is contrary to prior findings of Adams and Dijkstra (1966) who demonstrated a recall decrement using intervals of up to three minutes. Decrements were noted in that study at intervals as short as five seconds. Thus, the longest interval used in the current study--60 seconds--should have been sufficiently long to demonstrate this effect. Posner and Konick (1966b) reported significant decrements in both their visual and kinesthetic tasks, with time intervals as short as five seconds. Posner (1967) showed increasing absolute errors from zero to 20 seconds with a similar task. The algebriac error analysis of the present study was revealing of the predominant tendency of the Ss to overshoot the criterion force during the recall trial. This analysis also failed to indicate a decrement in recall over time. Two noted differences between the present study of motor-STM and the prior-referenced ones suggest themselves as possibly mediating the different results obtained. The first concerns the potential opportunity for rehearsal available to S during the retention intervals, and the second concerns the nature of the task employed in this study as compared to the prior ones.

Opportunity for rehearsal

Posner (1967) reported a recall decrement in a kinesthetic positioning task over a 20-second retention interval regardless of whether or not S had opportunity to rehearse. Rehearsal opportunity was defined in terms of the information-processing 'load' or "channel capacity" (Broadbent, 1958) used by the interpolated task over the retention interval. Decrements in recall were observed even when the retention interval was left unfilled. A visually-guided positioning task, however, showed no decrement over this same interval if it were unfilled, but increasing decrements as the loading of the interpolated task increased. On the basis of this evidence, Posner concluded that visual and kinesthetic tasks are coded by somewhat different operations, and that the coding of kinesthetic information involves more than verbal labels. Posner and Konick (1966b) compared forgetting for a visual location task (location of a circle along a line) and a kinesthetic positioning task (length of a movement made without visual guidance) as a function of the difficulty of an interpolated task. They reported no forgetting for visual location with an unfilled retention interval. For filled intervals, forgetting was a function of the difficulty of the interpolated task. For the kinesthetic task, the difficulty of the interpolated task was unrelated to forgetting, as it occurred in all cases. Either the kinesthetic trace was not facilitated by the rehearsal opportunities provided, or the activities which were designed to deny rehearsal in the Posner and Posner and Konick studies were ineffective for this purpose.

Forgetting was demonstrated by Adams and Dijkstra (1966) with a linear positioning task, carried out without visual guidance, although the retention interval was always unfilled (the S waited passively during the interval).

These three studies indicate that the opportunity for rehearsal should play a relatively minor role in motor-STM. However, given the unique characteristics of the present motor task compared to those used previously, it would appear worthwhile to investigate in greater detail the effect of a variety of interpolated activities on the retention of the criterion response. In the context of past studies, one would not expect the denial of rehearsal opportunity to produce significant changes in recall accuracy.

Properties of the motor tasks

Undershooting of the criterion movement is a response set characteristically found in movement tasks in which the extent of movement exceeds approximately five centimeters. Movements smaller than this result in characteristic overshooting tendencies (Brown, Knauft, and Rosenbaum, 1948).

McCormack (1964) reported that, in general, subjects tend to overshoot short distances and undershoot longer ones. With vertical positioning movements, in particular movements from top to bottom, there is a tendency to overshoot both long and short distances. Considerable ambiguity exists in vertical positioning tasks. Lazer and Williams (1959), cited by McCormack, conclude that 'natural' movements or population stereotypes associated with left-and-right movements (i.e., the horizontal dimension) is non-existent for vertical positioning tasks. Ellson and Wheeler (1947) have found for a continuous tracking task, a tendency to undershoot longer stimulus movements, and overshoot shorter ones. This has been termed the "range effect". Fitts (1951) notes this same "range effect" in discrete distance and force tasks. Jenkins (1947) found overshooting to characterize forces less than 20 pounds and undershooting for forces greater than 20 pounds. Thus the data of these prior studies demonstrates an interaction between the task characteristics and over- or undershooting response tendencies.

The present task has evidenced a characteristic response set of overshooting. Only two of the 20 Ss in Experiment I responded with undershooting. The extent of movement for this vertical positioning task was less than one hundredth of a centimeter, and the force ranges were below ten pounds. Thus, the overshooting tendency reported in the present study is in good agreement with expectations from prior findings of motor-skill studies.

The Adams and Dijkstra task was a horizontal positioning movement of at least ten centimeters in length, ranging in four centimeter steps to 34 centimeters. The negative algebraic error scores noted for this study indicate that the typical response set was one of undershooting. That is, the majority of the Ss reproduced a linear positioning movement which was smaller or of lesser extent than the initial criterion movement. This type of undershooting is also consistent with previous findings for horizontal positioning movements.

The Posner studies used an angular-positioning task which involved movements of five to 240 centimeters in length. Given prior findings with similar tasks, a response tendency of undershooting would be a strong prediction. Unfortunately, algebriac error scores were not reported in the Posner studies, so this response set characteristic cannot be unequivocally determined at this time. However, a preliminary study by the present author in which a similar angular-positioning task to that used by Posner was employed, resulted in marked undershooting on the part of most Ss.

Thus the Adams and Dijkstra study, and the Posner studies inferred forgetting from the results of tasks which apparently were characteristically responded to by undershooting. Over the retention intervals investigated in these studies, the characteristic response set of undershooting may have contributed to their "forgetting" in the following manner: Assume that some residual component or representation of the criterion-movement response is stored in the form of a code or trace, perhaps visually, verbally, or kinesthetically.[1] Reproduction of the criterion-movement is then accomplished by comparing the stored trace with the ongoing movement occurring during

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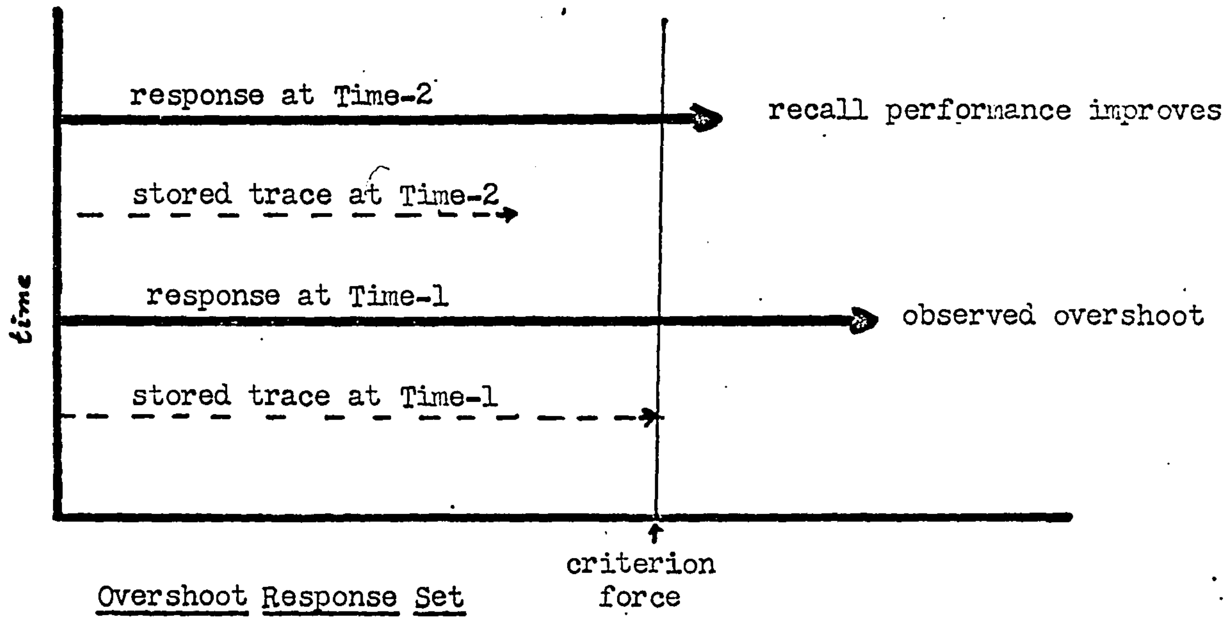
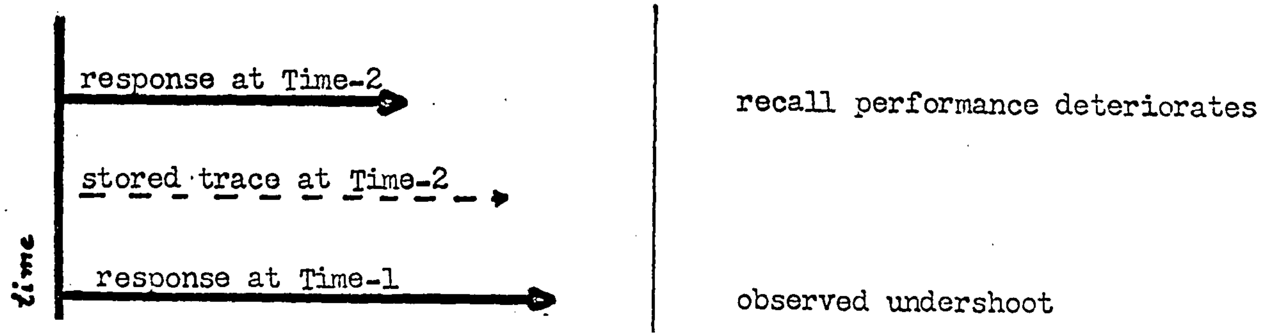
[1] Posner and Konick suggest a visual image as the most likely mechanism of storage. Both the Adams and Posner studies appear to have ruled out verbal coding as practical contenders, since verbal rehearsal was implicitly available in their studies, and still forgetting occurred.

the recall trial. Thus, if the response set for any particular task were one of undershooting, and there is decay or weakening of the stored trace over time, the effect will be that S matches the recall movement with a weak trace--i.e., he matches the recall movement against a representation of the criterion movement which now indicates lesser force, or lesser magnitude or lesser extent than was actually accomplished. Since S characteristically undershoots, the effect is to increase the apparent error over time. That is, with time, S is matching the recall movement against a continually-weakening trace, but characteristically undershooting that trace. He thus diverges further and further with time from the actual criterion movement, and exhibits an increasing negative algebraic error (and an increasing absolute error).

On the other hand, if the characteristic response set were one of overshooting, as in the present study, the decay or weakening of the stored trace will result in an apparent increase in accuracy over increasing retention intervals. The more the trace decays or is degraded, the more closely the recall response tends to approximate the actual criterion response. These relationships are illustrated more clearly in Figure 7. The figure shows that the effect of overshooting a decayed trace is to bring the recall movement close to the value of the criterion movement. The effect of overshooting an undecayed trace is to introduce a large, positive algebraic error (and a large absolute error). On the other hand, undershooting an undecayed trace results in a relatively



Overshoot Response Set



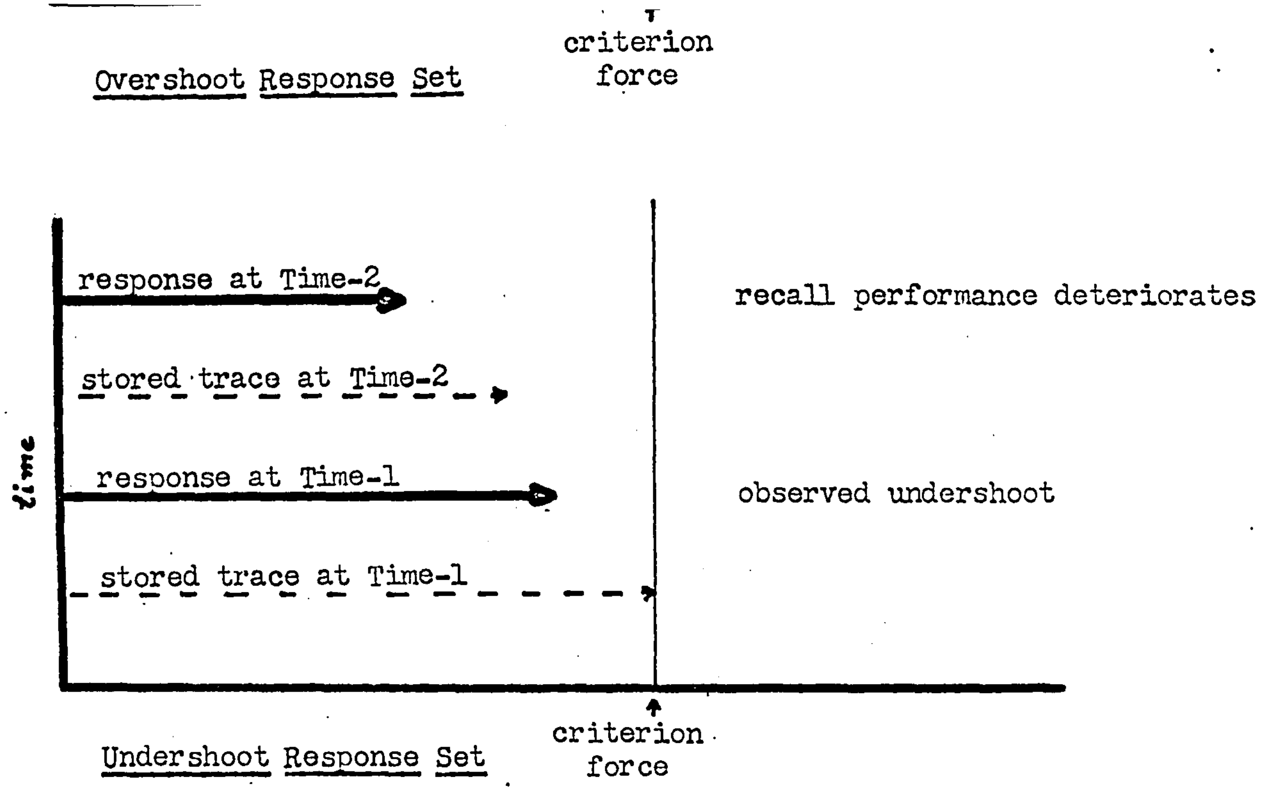


Fig. 7. The Assumed Function of Trace-Decay Over Time

Assumptions:

Performance measurement is always from the response to the criterion force.

The stored trace loses strength from Time-1 to Time-2.

The response set characteristic is stable (constant over time).

small negative algebraic error, as compared to the large negative error observed with a decayed trace.

The concept of a fading memory trace with time has been a cornerstone of one type of theory of forgetting in STM (e.g., Brown, 1958; Peterson and Peterson, 1959). The data for trace theory has been weighted by verbal tasks rather than motor tasks. But it should be stressed that decay theory has been advanced to accommodate a variety of findings with tasks other than verbal, so that its generality would appear wide. For example, in studies of psychophysical judgment, the S's overestimations of the second of two successive stimuli has been termed "negative time error." Fechner initially reported this effect in his studies of lifted weights, and proposed that the image of the first stimulus had faded or weakened by the time the second stimulus was presented. In comparison to the second, the first stimulus appeared weaker (Woodworth and Schlosberg, 1954).

Basing his conclusions on a set of auditory-discrimination studies, Stevens (1939) argued that the fading trace time-error was applicable to judgments of intensity but not to judgments of sensory quality. Thus when pitch was judged, time-error was absent. With loudness judged however, the classical negative time-error was observed. The essence of Stevens' argument was that tones differing in pitch have different loci in the auditory cortex, but tones differing in loudness have the same locus. The trace left by the first stimulus may fade or weaken, but it cannot shift its locus, i.e., change pitch.

Postman and Page (1947) demonstrated the typical undershooting associated with the negative time-error in a task of perceptual discrimination. They interpreted the weakening of the memory trace of the first stimulus to be due to the same mechanism which operates in retroactive interference (RI), but with the interfering event unspecified and unobserved.

Adams and Dijkstra (1966) clearly state that the results of their motor-STM study was consistent with the hypothesis of a decaying memory trace, which had become increasingly stable with reinforcement (repetition). There was opportunity for rehearsal since their Ss performed no other task during the retention interval, other than sitting quietly. However, Adams and Dijkstra feel that it was unlikely that prior activity, or the sitting behavior, would generate sufficient interference in this situation. It does not appear unreasonable, therefore, to make the concept of a fading trace in the manner suggested in Figure 7.

It is thus possible that the conclusions based upon previous research by Adams and Dijkstra (1966), Posner and Konick (1966b) and Posner (1967) are contaminated by their failure to consider response sets associated with their experimental tasks. That is, demonstration of forgetting or of no forgetting can be a task-related phenomenon in motor-STM. If this is the case, theoretical statements which attempt to relate motor-STM and verbal-STM may be premature and misleading, as verbal tasks seemingly are devoid of analogous response-set characteristics.

The following experiment will be directed toward a clarification of the role of opportunity for rehearsal during the retention interval upon recall of a criterion force. Thus the retention interval will be either filled or unfilled with a counting-backwards task, or left unfilled as in the present experiment. In addition, the response-set characteristics will continue to be evaluated for its effect on the _S_s memory performance.

CHAPTER IV

STUDY OF SHORT-TERM MOTOR MEMORY II. EFFECTS OF FILLED VERSUS UNFILLED INTERVALS ON RETENTION

The results of Experiment I generally indicated that the retention of a force response was not related to time in a simple manner. A logical course to follow would be to determine under what conditions a decrement in performance might be demonstrated, using the task studied in Experiment I. Therefore, the following experiment is concerned with the effects of a backwards-counting activity interpolated between the application of a visually-guided criterion force and the subsequent reproduction of that force without visual-guidance. Backwards-counting has been employed effectively in studies of verbal STM as an interpolated task which precludes rehearsal of a prior task (e.g., Peterson and Peterson, 1959). The effects of the interpolated activity were studied under three different retention intervals.

Method

Subjects

Twenty-four University of Hawaii undergraduate volunteers from an introductory psychology class participated for course credit. They had not participated in Experiment I of this study nor in any previous memory experiments. There were eleven males and thirteen females.

Apparatus

The same experimental apparatus as described in Experiment I was used. In addition, a 1500 cps auditory pulse, at the rate of one pulse per second was provided to pace the interpolated counting activity.

Experimental Design

A four-way, all within-Ss design was used, consisting of three levels of force, three retention interval,s two directions of movement, and filled versus unfilled retention intervals. Each S was required to respond to force levels 1, 2, and 3 using both Up and Down task directions. These force levels in turn were each associated with retention intervals of 4, 12, and 30 seconds. For half the trials, the intervals were left unfilled, and for the remaining half they were filled with the counting task. The presentation of Up or Down was systematically counterbalanced, as was the occurrence of the filled and unfilled retention intervals. Each force occurred three times during each block of nine trials, as did each retention interval. Thus, each S received a total of 32 trials during the course of the experiment.

Procedure

The procedures used were those of Experiment I, except for the addition of the counting-backwards activity. On half the trials, following application of the criterion force and offset of the digit signifying that force, S sat quietly until the presentation of the digit again occurred, signalling the start of the recall trial. On the remaining half of the trials, however, following application of the criterion force, S heard a three-digit number over the intercom system and simultaneously a 1500 cps tone began pulsing. These were the signals for S to (a) repeat the heard number and (b) begin counting-backwards from that number by three's. Upon the onset of the digit-signal to recall the criterion force, S stopped counting. Complete Subject's Instructions are given in Appendix 2.

Results

The Ss' responses were recorded as previously described in Experiment I and an analysis of both absolute and algebraic errors was again made. Table 3 provides a summary of the means for the variables under consideration. Again, as in Experiment I, the algebraic errors were large and positive, indicating the predominant tendency of the Ss to overshoot the criterion force during the recall trial. It can also be seen in Table 3 that the interpolated activity of counting was associated with larger errors for both absolute and algebraic scores than was the unfilled interval. The other variable of major interest, retention intervals, shows decreasing errors of both types associated with the longer intervals, tending to support trends in this direction noted in Experiment I for algebriac errors. Figure 8 shows a plot of both types of errors as a function of interpolated activity and length of the retention interval. It can be seen that a more rapid decrease in errors with time characterizes the unfilled

Table 3

Mean Absolute and Algebraic Errors in Millimeters
For All Levels of Task Direction, Interpolated
Interval, Force, and Time

Direction

Up	Down
5.61 (5.15)	5.99 (5.40)

Interpolated Interval

Unfilled	Filled
4.90 (4.36)	6.71 (6.20)

Force

1	2	3
4.85 (4.63)	5.63 (5.17)	6.93 (6.03)

Time

4	12	30
6.23 (5.79)	5.64 (5.27)	5.54 (4.76)

NOTE: Algebraic errors are in parenthesis

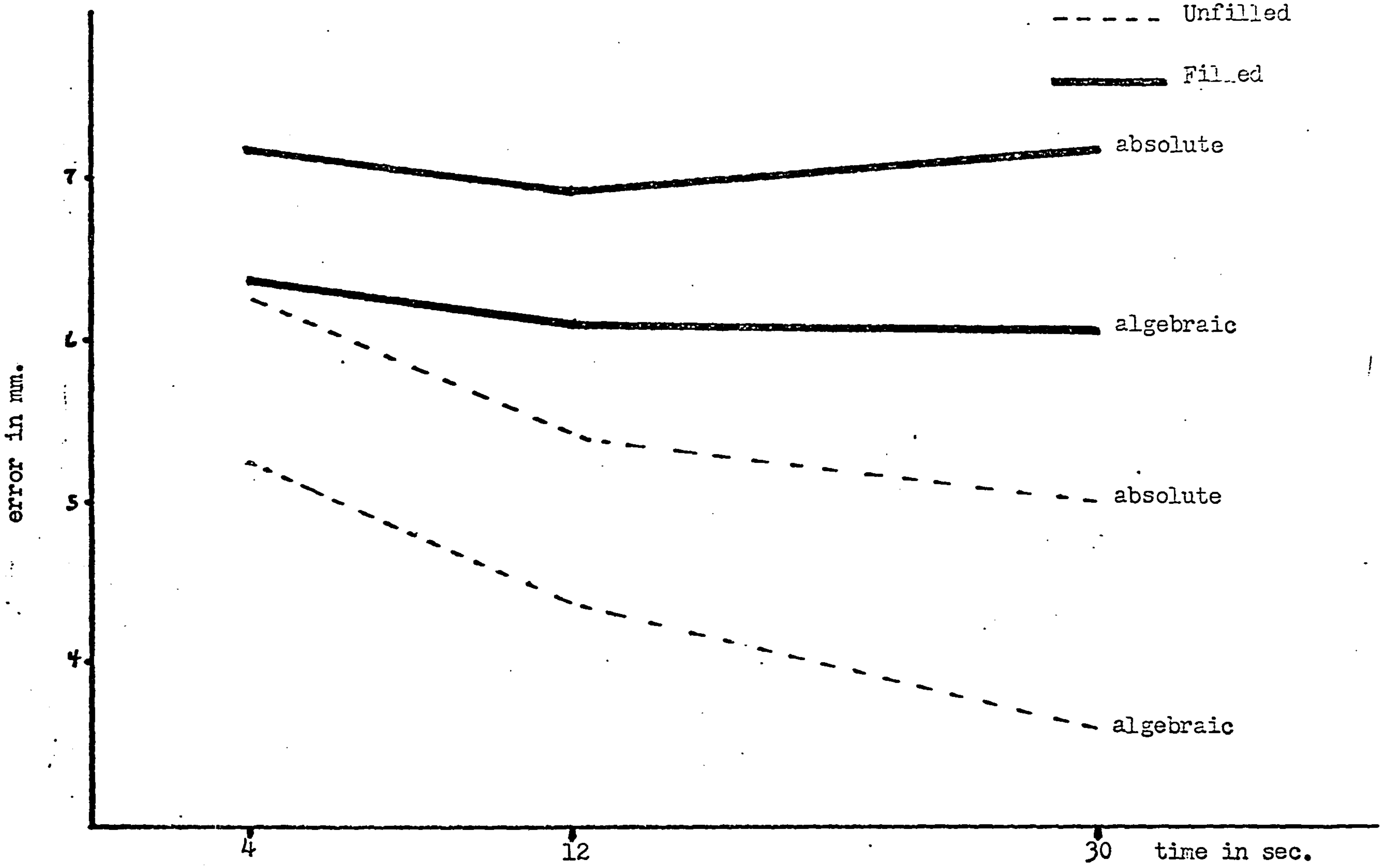


Fig. 8. Absolute and Algebraic Errors for Filled and Unfilled Retention Intervals

retention intervals.

Table 4 presents the results of a four-way analysis of variance performed on both the absolute and the algebraic errors. Both analyses yielded comparable results, with the exception of a significant three-way interaction noted only for the algebraic errors. It can be seen that the main effect of the type of interpolated activity was highly significant for both analyses, and that the retention interval main effect and linear trend for this variable were both significant. The interaction of interpolated activity and retention intervals was not significant however, indicating that the trend noted in Figure 8 was not significant.

Thus, in the present results there is the anomalous finding that performance improved significantly with increasing retention intervals, regardless of whether S̲ was actively engaged in a highly-demanding counting task during the interval, or whether he merely waited passively. It is evident that counting-backwards adds a relatively constant and significant increment to the error scores at all retention intervals.

Table 4

Analysis of Variance of Absolute and Algebraic Errors on Filled vs Unfilled Retention Study

		Absolute			Algebraic		
Source	df	MS	F	P	MS	F	P
Ss	23	120.76			245.29		
Up/Down(A)	1	31.70	1.12		13.18	0.38	
Ss x A	23	28.30			34.26		
Unfilled/Fill(B)	1	704.64	62.80	.001	730.91	46.97	.001
Ss x B	23	11.22			15.56		
Force(C)	2	315.84	14.96	.001	143.06	4.86	.05
Linear	1	618.95	29.32	.001	280.98	9.54	.01
Quadratic	1	12.73	0.60		5.16	0.18	
Ss x C	46	21.11			29.44		
Time(D)	2	40.17	4.51	.05	76.47	7.61	.01
Linear	1	69.17	7.76	.01	152.93	15.22	.001
Quadratic	1	11.18	1.25		0.003	0.00	
Ss x D	46	8.91			10.05		
A x B	1	0.73	0.10		12.58	1.41	
Ss x AB	23	7.65			8.92		
A x C	2	40.30	3.42	.05	43.09	3.30	.05
Ss x AC	46	11.78			13.04		
A x D	2	17.17	1.66		24.62	1.72	
Ss x AD	46	10.32			14.33		
B x C	2	15.04	1.09		26.57	1.69	
Ss x BC	46	13.77			15.75		
B x D	2	15.16	0.89		39.60	2.25	
Ss x BD	46	16.94			17.60		
C x D	4	14.12	1.71		23.29	2.33	
Ss x CD	92	8.26			9.98		
A x B x C	2	8.88	0.77		50.94	3.59	.05
Ss x ABC	46	11.56			14.20		
A x B x D	2	23.73	2.68		30.41	2.98	
Ss x ABD	46	8.84			10.85		
A x C x D	4	23.01	2.17		28.67	1.99	
Ss x ACD	92	10.58			14.43		
B x C x D	4	18.34	1.83		17.75	1.33	
Ss x BCD	92	10.03			13.30		
A x B x C x D	4	1.75	0.22		8.64	0.99	
Ss x ABCD	92	8.12			8.77		

Discussion

The main findings of Experiment I were supported in the present study. In particular, the failure to find deterioration of recall performance over the retention intervals employed is consistent with the prior results. Indeed, the present study has demonstrated that performance may actually improve significantly over increasing retention intervals. The characteristic response of overshooting--indicated by the high positive algebraic errors--was also noted in this study.

The fact that Ss' recall performance improved over time is consistent with the task-related, response-set interpretation and fading trace theory introduced earlier. The findings are not consistent with the results of Posner's studies. In his kinesthetic task, Posner observed that forgetting occurred regardless of the nature of the interfering tasks which controlled the opportunity for rehearsal. He thus concluded that kinesthetic tasks were coded differently than visual tasks and were unaffected by the interpolated tasks.

The findings which must be accounted for in the present study are (a) the significant overall increase in errors following counting-backwards, indicating that that task is somehow interacting with the stored trace of the criterion force and (b) the failure to find an increasing recall decrement for either filled or unfilled intervals. It would appear that the conjunction of these two findings cannot be handled by the simple consideration of the preclusion of rehearsal, or by the amount of channel capacity available for information-processing.

The significant effect of the interpolated counting activity on recall performance is of considerable importance. The numerical operations involved in counting-backwards by threes would appear to be quite different from the application of the criterion force involved. Therefore, the role of the interpolated task may be nonspecific in nature. Talland (1967) has concluded that the operation of counting-backwards is to somehow distract the S from his orientation to the memory task. The basis of this distraction may be due to any number of factors. An analysis of results of studies specifically designed to study distraction effects indicated that distracting stimuli are overcome by the use of surplus muscular activity. "Competition between two S-R patterns builds up muscular tension, clearly visible in the wrinkled brow and rigid jaw that are usually regarded as the mark of strong voluntary attention," (Woodworth and Schlosberg, 1954, p. 86).

The counting activity required of the present Ss clearly had the characteristics of a distraction task. While the Ss were required to perform the counting activity accurately, they also were aware that the recall test would occur and that that was an important task. Therefore, it can be assumed that increased muscle tension may have resulted from the interpolated counting activity.

It has been frequently reported that the introduction of muscle tension in learning situations tends to facilitate performance (Woodworth and Schlosberg, 1954). After a thorough review of the literature, McGeoch and Irion (1952, p. 232) concluded that muscle tension, regardless of whether it is induced experimentally or whether it occurs spontaneously, tends to be positively correlated with rate of learning. In attempting to account for the effects of this variable in learning, Block (1936) concluded that increased tension may facilitate learning by providing a richer context of proprioceptive stimulation, thus making the stimulus more "vivid" or intense. Since it has been frequently demonstrated that variables which influence learning also are important in research in memory (Melton, 1963), the influences of muscle tension are appropriate to consider within the context of the present discussion.

One might question how the effect of increasing muscle tension might influence performance in the present experiment. The conclusion of Block, that muscle tension results in an intensification of the stimulus seems worth considering. If the stored stimulus _trace_ of the criterion force were made more intense, due to induced muscle tension, than during the subsequent recall test the overshooting response-set would result in a larger error response than would be the case without this muscular tension. This is because the _S_ is now comparing the recall force with a strengthened or enhanced memory trace, but continuing to overshoot that trace. It is thus suggested that generalized muscle tension may result in the enhancement or intensification of a stored motor trace; in effect, there appears to be a summation of the stored trace and the kinesthetic components of the generalized muscle tension. This suggests an active interaction of the interpolated activity and the criterion trace. Forgetting in motor-STM is thus tentatively postulated to be a dual process, reflecting effects of (a) trace strength and (b) trace interference, in the form of a direct alteration of the trace by the interpolated activity (Barnes and Underwood, 1959).

The following experiment will explore the implications of the above view by a manipulation of the characteristics of the interpolated tasks, in an attempt to determine whether the criterion task is specifically sensitive to particular interpolated task characteristics.

CHAPTER V

STUDY OF SHORT-TERM MOTOR MEMORY III

RETROACTIVE INTERFERENCE EFFECTS

The following experiment is concerned with assessing effects of an interpolated motor task on recall of a previous motor task. Specifically, recall of a criterion force when a second force occurs during the retention interval is contrasted with recall performance observed when the interpolated activity is counting-backwards and when it is merely sitting quietly. Characteristics of the interpolated force are varied along two dimensions (*a*) force magnitude, as compared with the criterion force--i.e., either a lesser or a greater force magnitude than the criterion force and (*b*) force direction, with respect to the criterion force--i.e., either aforce applied in the same direction or in the opposite direction to the criterion force.

Method

Subjects

Twenty-four University of Hawaii undergraduate volunteers from an introductory psychology class participated for course credit. There were five males and nineteen females, none of whom had previously participated in this or any other memory study.

Apparatus

The identical apparatus as described in Experiments I and II was used.

Experimental Design

A within-Ss design was used to test for the effects of criterion force magnitude (Forces 2 and 4), criterion force direction of movement (Up-Down), interpolated-force relative direction (same or opposite direction of criterion force) and interpolated force magnitude (either the production of a force of greater magnitude or of lesser magnitude than the criterion force, or of no force). In the case of no force, Ss either counted backwards during the retention interval or sat passively. Each S was required to respond to the two criterion force levels in both an Up and a Down direction. Each of these responses in turn was associated with an interpolated force task which was either one magnitude greater (3, 5) or one magnitude less (1, 3) than the criterion force. On half the trials, a "zero" force was required during the retention interval. For half of these zero trials, S sat passively until the recall test, and on the remaining half he counted backwards from a number presented by E. Table 5 presents in greater detail the combinations of all variables used in the present study. It shows a total of 32 unique conditions, presented to S on 32 unique trials. These were divided into four blocks of eight trials, and within each block Up and Down criterion forces were alternated, as were force levels. The passive and active control (zero-sit and zero-count) occurred four times within each block and were counterbalanced so that each occurred first and last equally often within each block. A 5 x 5 Latin square which minimized order effects was generated (Fisher, 1947) and 20 unique orders of the four blocks of eight trials were obtained by using all rows and columns of this square. An additional four orders were selected at random from this square.

Procedure

The Ss were required to produce a visually-guided, criterion-force, followed in four seconds by either a second visually-guided force response of greater or lesser magnitude than the criterion force, or by a zero force. In the latter case, the digit "zero" was displayed and the S merely continued to grip the control knob, but applied no force. On half of these zero trials, simultaneous with the presentation of the zero, E read a three-digit number over the intercom. S immediately repeated the number and began counting backwards by three's as fast and accurately as possible, without external pacing, until the criterion digit reappeared, signifying recall. Thus, this counting duration was 16 seconds, preceded by 4 seconds of sitting passively, while the total passive-sitting duration was 20 seconds. The interval from offset of an interpolated force to the recall signal for the criterion force was 10 seconds. In addition, production of the interpolated force required six seconds and there was a four-second passive-waiting condition immediately preceding application of the interpolated force. Thus for all cases, the interval from offset of the signal to apply the criterion force to onset of the signal to recall that force

Table 5

Schematic of Experiment III

Interpolated Activity	UP		DOWN	
	Force 2	Force 4	Force 2	Force 4
Greater Force, Same Direction	Up 3	Up 5	Down 3	Down 5
Lesser Force, Same Direction	Up 1	Up 3	Down 1	Down 3
Greater Force, Opposite Direction	Down 3	Down 5	Up 3	Up 5
Lesser Force, Opposite Direction	Down 1	Down 3	Up 1	Up 3
Zero Force (unfilled)	sit sit	sit sit	sit sit	sit sit
Zero Force (filled)	count count	count count	count count	count count

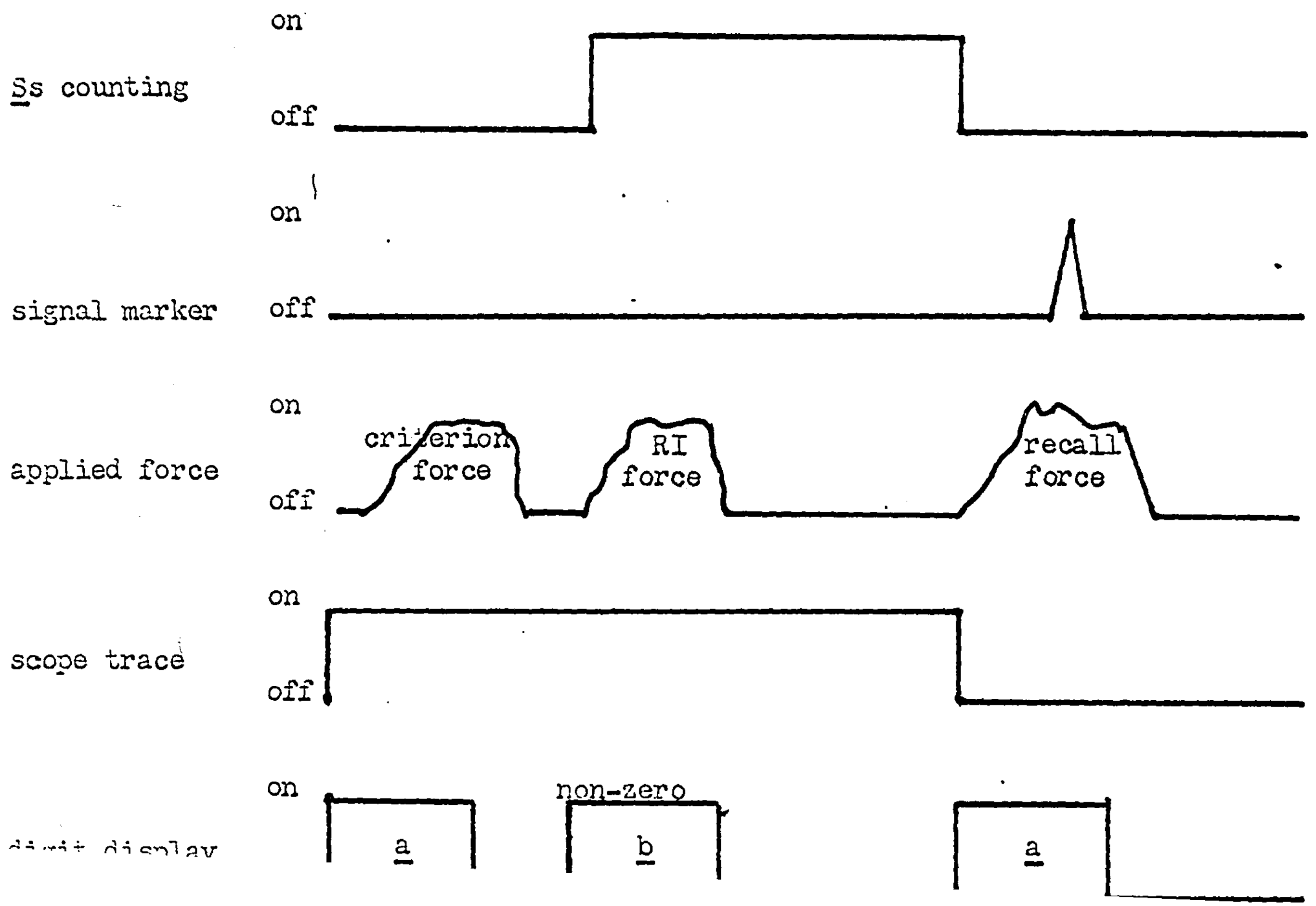
Note--The designation 'Up 3', for example means that <u>S</u> was required to produce a visually-guided force of level 3, in the UP direction, during the retention interval.

was 20 seconds. Figure 9 shows a time line of these relationships. Note that S was informed that he would be required to reproduce the first force applied. Appendix 3 provides the complete Subject's Instructions.

Results

Performance of the Ss was recorded as in previous experiments. Table 6 provides a summary of the means for all levels of all variables. The variables of major interest are interpolated-force relative direction and interpolated-force relative magnitude. It is obvious that effect of relative direction between the interpolated force and the criterion force was of very small magnitude. However, it is apparent that the variable of interpolated force-relative magnitude--whether the S was required to apply a force of greater magnitude, of lesser magnitude, or count, or sit during the retention interval--had appreciable effects on recall. Note the ordering of effects: largest errors were associated with 'counting', followed in turn by 'greater force', 'lesser force', and finally 'sitting'. Also note that algebraic errors were again large and positive in sign, indicating the characteristic overshoot response by Ss.

Table 7 presents the results of an analysis of variance performed on both the absolute and algebraic errors. For this analysis, only the trials on which S applied an interpolated force are considered, in order to clarify the interaction effects, if any. The 'zero' trials are considered in


Ss counting
signal marker
applied force
scope trace
digit display
on
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criterion force
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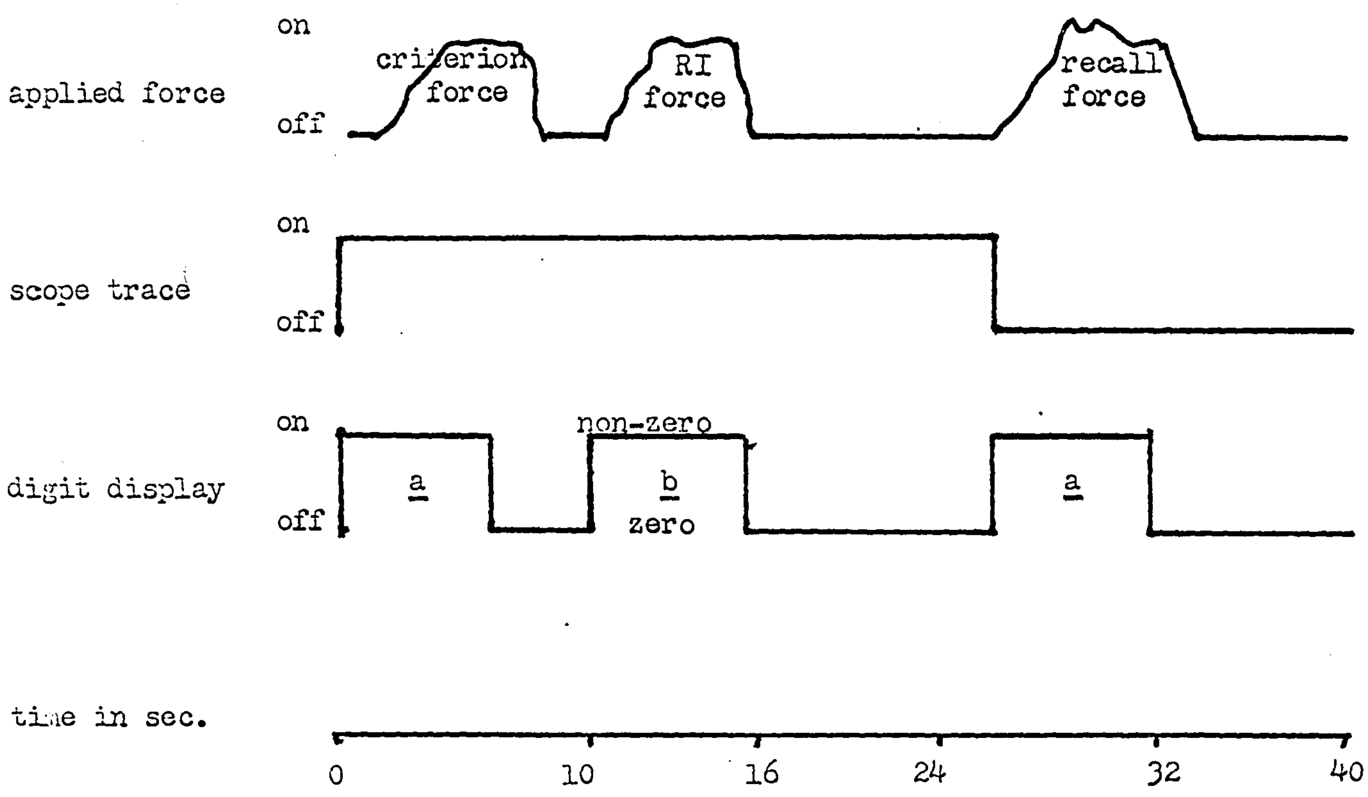


Fig. 9. Time-line of Events Occurring in Experiment III, Criterion Force Digit indicated by a, Retroactive Firce by b.

Table 6

Mean Absolute and Algebraic Errors in Millimeter For All Levels of Task Direction, Force, Task Similarity, and Interpolated Activity

Direction	
Up	Down
6.01 (5.13)	5.41 (4.31)

Force	
2	4
4.91 (4.28)	6.51 (5.17)

Interpolated-Force Relative Direction (Task Similarity)	
Same	Opposite
5.61 (4.75)	5.81 (4.70)

Interpolated-Force Relative Magnitude			
Greater	Count	Sit	Lesser
5.97 (5.22)	6.45 (5.90)	4.52 (3.23)	4.71 (3.05)

Note--Algebraic Error is in Parenthesis

Table 7

Analysis of Variance of Absolute and Algebraic Errors of the Retroactive Interference Study

		Absolute			Algebraic		
Source	*df*	*MS*	*F*	*p*	*MS*	*F*	*p*
Ss	23	1305.84			140.00		
Up-Down(A)	1	69.78	4.66	.05	112.34	3.23	
Ss x A	23	14.98			34.88		
Force(B)	1	414.79	29.80	.001	138.60	6.91	.05
Ss x B	23	13.92			20.06		
Task Similarity(C)	1	0.45	0.03		21.42	0.83	
Ss x C	23	13.68			25.89		
Greater-Less(D)	1	152.89	10.49	.01	451.29	40.04	.001
Ss x D	23	14.57			11.27		
A x B	1	11.59	1.24		29.65	1.60	
Ss x AB	23	9.37			18.50		
A x C	1	55.89	7.25	.05	69.10	9.30	.01
Ss x AC	23	7.71			7.43		
A x D	1	5.34	0.60		1.58	0.12	
Ss x AD	23	8.88			13.56		
B x C	1	12.65	1.62		46.55	3.13	
Ss x BC	23	7.82			14.71		
B x D	1	65.26	8.24	.01	48.40	3.74	
Ss x BD	23	7.92			12.95		
C x D	1	29.43	2.13		113.45	7.19	.05
Ss x CD	23	13.83			15.77		
A x B x C	1	3.36	0.27		6.28	0.36	
Ss x ABC	23	12.63			17.39		
A x B x D	1	17.04	1.62		16.69	1.09	
Ss x ABD	23	10.54			15.37		
A x C x D	1	0.00	0.00		15.79	0.72	
Ss x ACD	23	13.97			21.80		
B x C x D	1	68.77	5.55	.05	105.92	6.32	.05
Ss x BCD	23	12.39			16.75		
A x B x C x D	1	26.30	1.54		69.46	2.60	
Ss x ABCD	23	17.04			26.74		

separate analysis. It can be seen in Table 7 that the interpolated-force relative magnitude was highly significant for both types of errors, but that interpolated-force relative direction was not significant. This latter variable did interact significantly, however, with criterion-force direction, criterion-force level, and interpolated-force relative magnitude for both types of errors. In addition, there was a significant interaction with interpolated-force relative magnitude for algebraic errors only.

Figure 10 illustrates these effects of criterion-force direction and interpolated-force similarity (relative direction). It can be seen that criterion forces Down were less influenced when the interpolated-force occurred in the opposite direction, whereas the reverse was true for Up forces. Figure 11 presents the interaction between interpolated-force similarity and interpolated-force relative magnitude. It is apparent that 'opposite' direction forces produced greater differences between the relative magnitude effects than did the 'same' direction forces. Note that 'greater' produces consistently larger errors than 'lesser' in all cases, however. It should be noted that only the algebraic interaction was statistically significant for these effects.

Figure 12 presents the relationship between interpolated-force similarity, interpolated-force relative magnitude, and levels of the criterion-force for the algebraic analysis. It can be seen that 'lesser' relative magnitudes produce smaller errors in all cases except for Force 4 with the interpolated

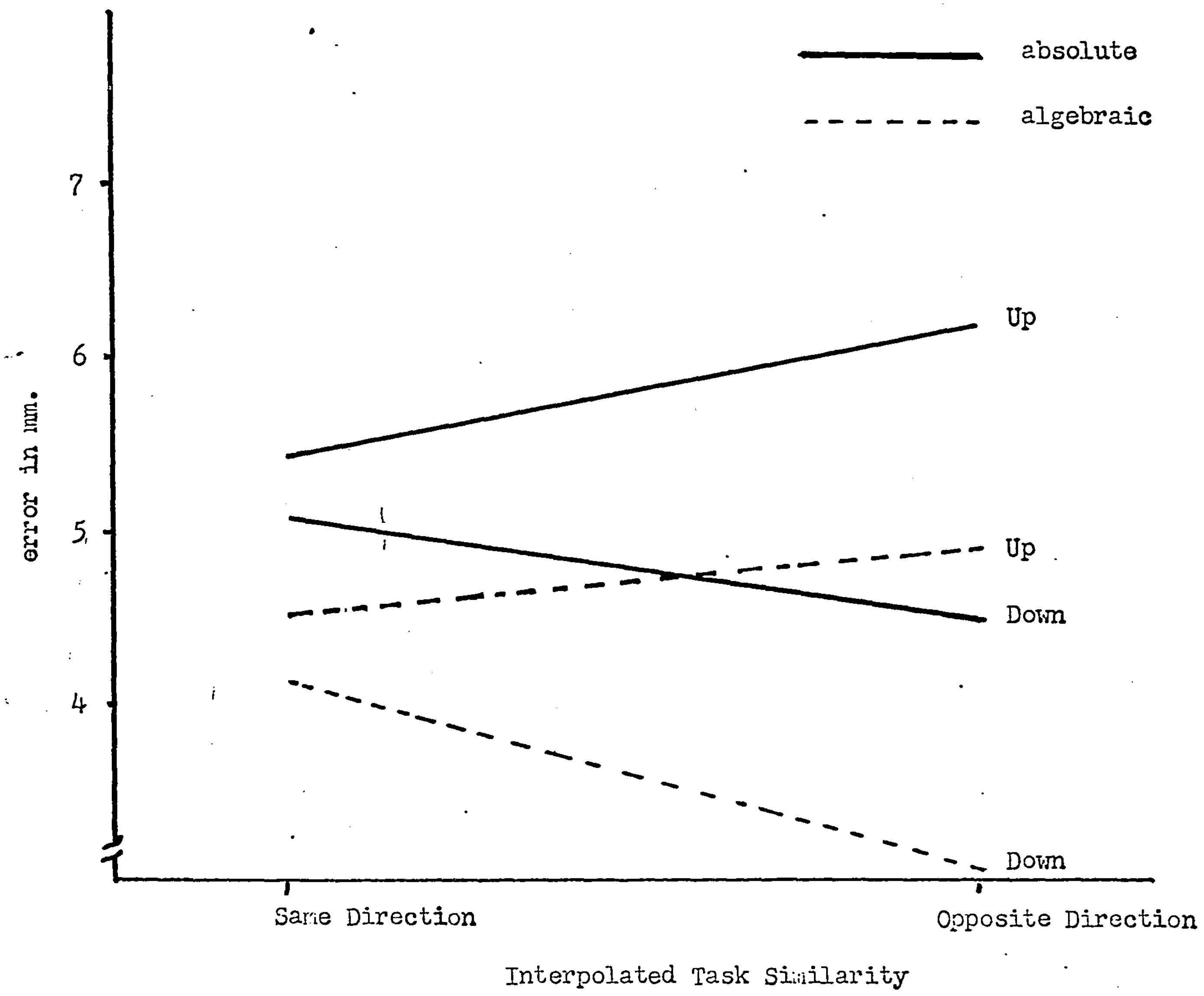


Fig. 10. Absolute and Algebraic Errors for Criterion-Force Direction and Interpolated-Force Direction Similarity in Retroactive Interference Study

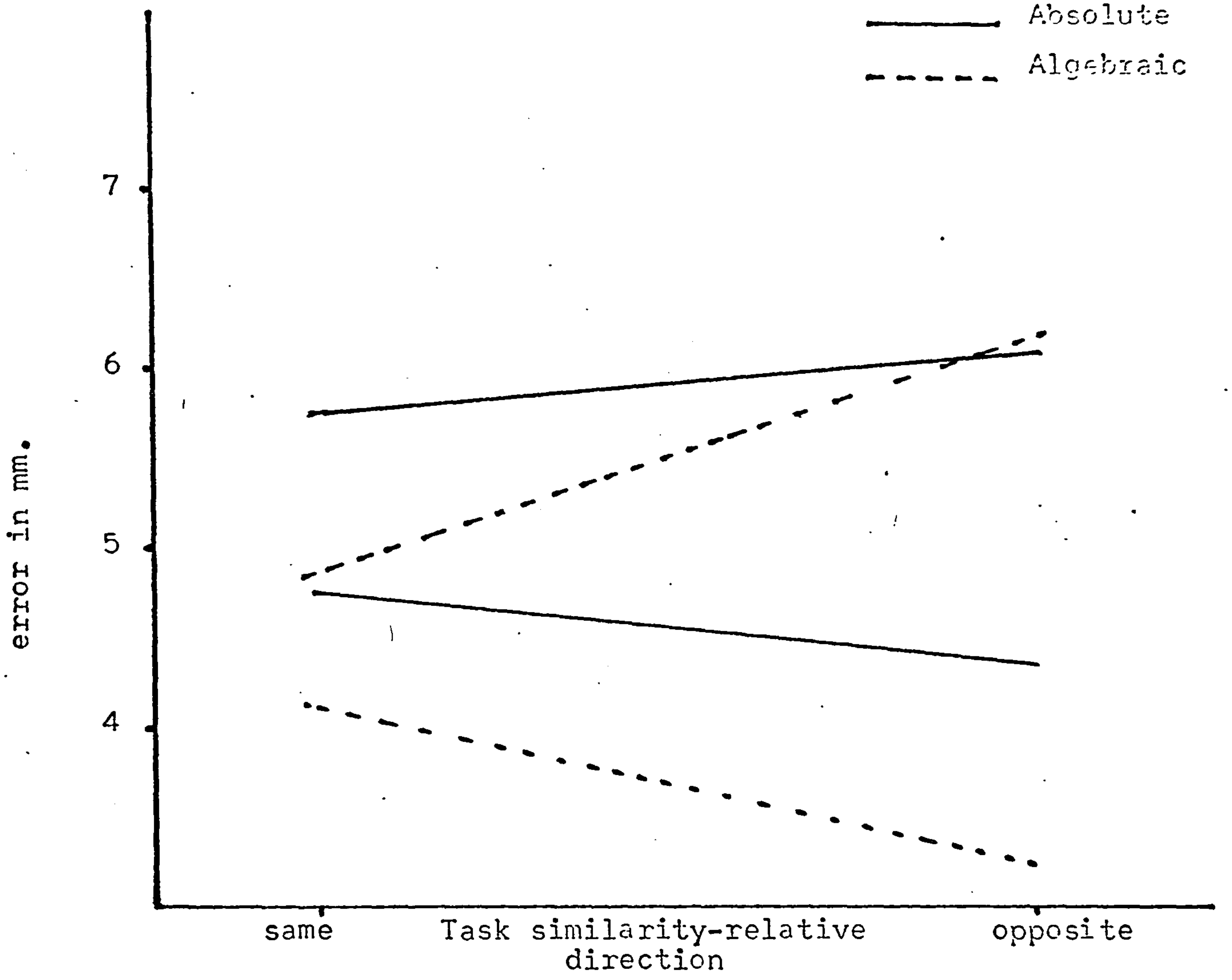


Fig. 11. Absolute and Algebraic Errors for Interpolated-Force Relative Magnitude and Relative Direction to Criterion Force

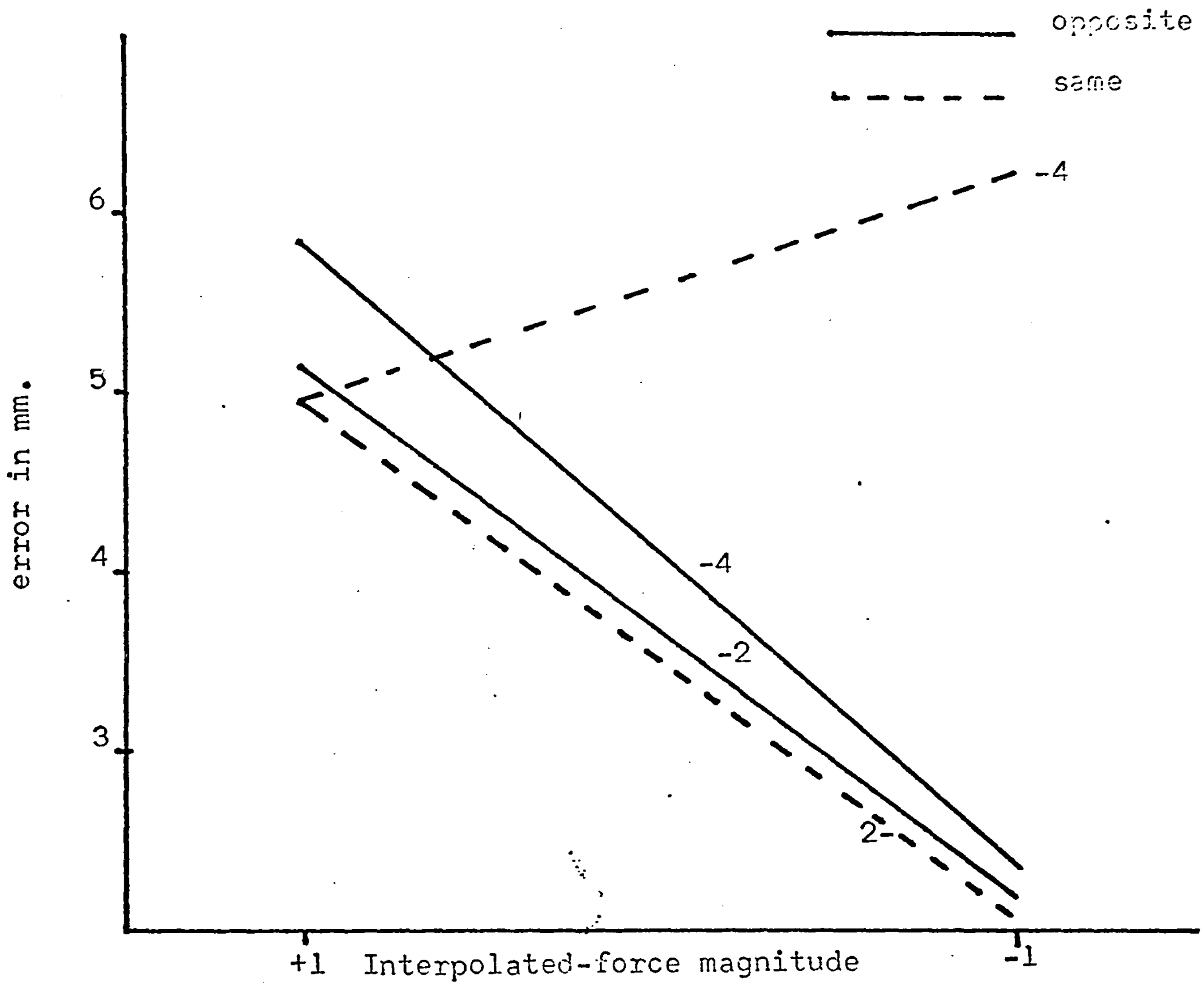


Fig. 12. Mean Algebraic Errors of Interpolated-Force Similarity and Interpolated Force Relative Magnitude.

force in the same direction. Note that this relationship was significant for both analyses.

A comparison was made between the errors associated with interpolated-forces of greater and lesser relative magnitude and the counting and passive control conditions. An overall analysis of variance indicated that the four conditions were significantly different, for both absolute and algebraic errors, $\underline{F}s\ (3, 46) \geq 16.91$, $\underline{p} < .001$. A Neuman-Keuls test was then used to test for significance of differences between all pairs of conditions, and is summarized in Table 8. It can be seen that for both absolute and algebraic errors, the counting task produced a significantly larger error than either the lesser or the passive control condition. In addition, for the algebraic error analysis, greater magnitudes differed significantly from both the passive control and the lesser magnitude.

Discussion

The results of the present experiment indicate that retroactive interference effects can be demonstrated in motor STM. In general, the manner in which the interpolated force exerts itself in the RI design appears to be in a directional-biasing of the force response during the recall test. Thus, interpolated forces which are greater in magnitude than the criterion force produce significantly larger recall forces than do interpolated forces smaller than the criterion force. It should be pointed out that this phenomenon of directional-biasing is related to a somewhat older phenomenon of

Table 8

Comparison of Interpolated Task Mean Absolute and Algebraic Errors Using Neuman-Keuls Test

	Control	Greater	Lesser	Sit
Control		1.19 (1.29)	4.24* (5.96)**	4.71** (6.33)**
Greater			3.09 (4.44)*	3.54 (4.78)**
Lesser				0.05 (0.38)
Sit				

Note: $p < .05$ = *

$p < .01$ = **

psychophysics, called "assimilation" by Lauenstein (1933), as cited in Woodworth and Schlosberg (1954). He found that the trace of the standard stimulus was 'attracted upward' toward a loud interpolated stimulus, and downward toward a soft interpolated stimulus. Subsequent research confirmed these findings, and has led to the incorporation of methodological procedures in the presentation of stimuli to control for their effects (Woodworth and Schlosberg, 1954).

It is reasonable to consider the observed directional-biasing effects within the context of interference theory. As postulated in the previous experiment, the activity of counting backwards interacted or summated with the criterion-force trace to produce a more intense trace. Thus the production of the criterion force during recall was considerably larger than normal. The situation presented by an interpolated force task can be considered in a similar manner. An interpolated force of greater magnitude than the criterion force interacts or summates with the criterion force trace to produce a trace which represents some combination of the strengths of both traces combined, perhaps the mean strength. This results in a recall response which is considerably greater than the normal recall. On the other hand, if the interpolated trace is of lesser strength than the criterion trace, the mean trace intensity is reduced, and the resulting recall response is of lesser magnitude than normal. This viewpoint is representative of that type of interference theory in which traces are considered as non-independent

(Barnes and Underwood, 1959).

The demonstration of interference effects in motor STM has not previously been accomplished. It is possible that the manner in which the interpolated task influences recall has been overlooked in previous research. An attempt to demonstrate interference as a function of the similarity of the interpolated task to the criterion task was unsuccessful. Thus the main effects of 'same' direction (up-up or down-down) as compared to opposite direction (up-down or down-up) was not statistically significant. This is consistent with findings reported by Blick and Bilodeau (1963) who suggested that similar skill components were involved in both their same and opposite tasks (clockwise and counterclockwise rotation). They subsequently concluded that since their task was a very simple, discrete movement, a demonstration of interference would be difficult. While the present force application task was also relatively simple, the writer sees no compelling necessity to consider task complexity in order to account for interference phenomena in the present discussion. It seems likely that with the present task, other dimensions associated with trace storage, i.e., the intensity dimension of the force application, is a more important variable. Thus, the manner in which the interpolated task influences the criterion task, which has been termed "directional-biasing", may become crucial in further studies of motor STM.

The following study was designed to assess the sensitivity of the present force task to interference effects resulting from force tasks occurring prior to the criterion task. Standard proactive interference procedures are used to investigate effects of production of a force immediately prior to the criterion force, on the subsequent recall of that criterion force.

CHAPTER VI

STUDY OF SHORT-TERM MOTOR MEMORY IV
PROACTIVE INTERFERENCE EFFECTS

The following experiment is concerned with assessing the effects of a prior task on the subsequent recall of a force response. Results from the RI study of Experiment III indicate that a direct~~io~~nal-biasing effect is basic to the operation of RI in motor STM. The following study seeks to determine the manner in which PI operates in motor STM.

Method

Subjects

Twenty-four University of Hawaii undergraduate volunteers from an introductory psychology class participated for course credit. There were twenty females and four males. No one had served in any of the prior memory experiments.

Apparatus

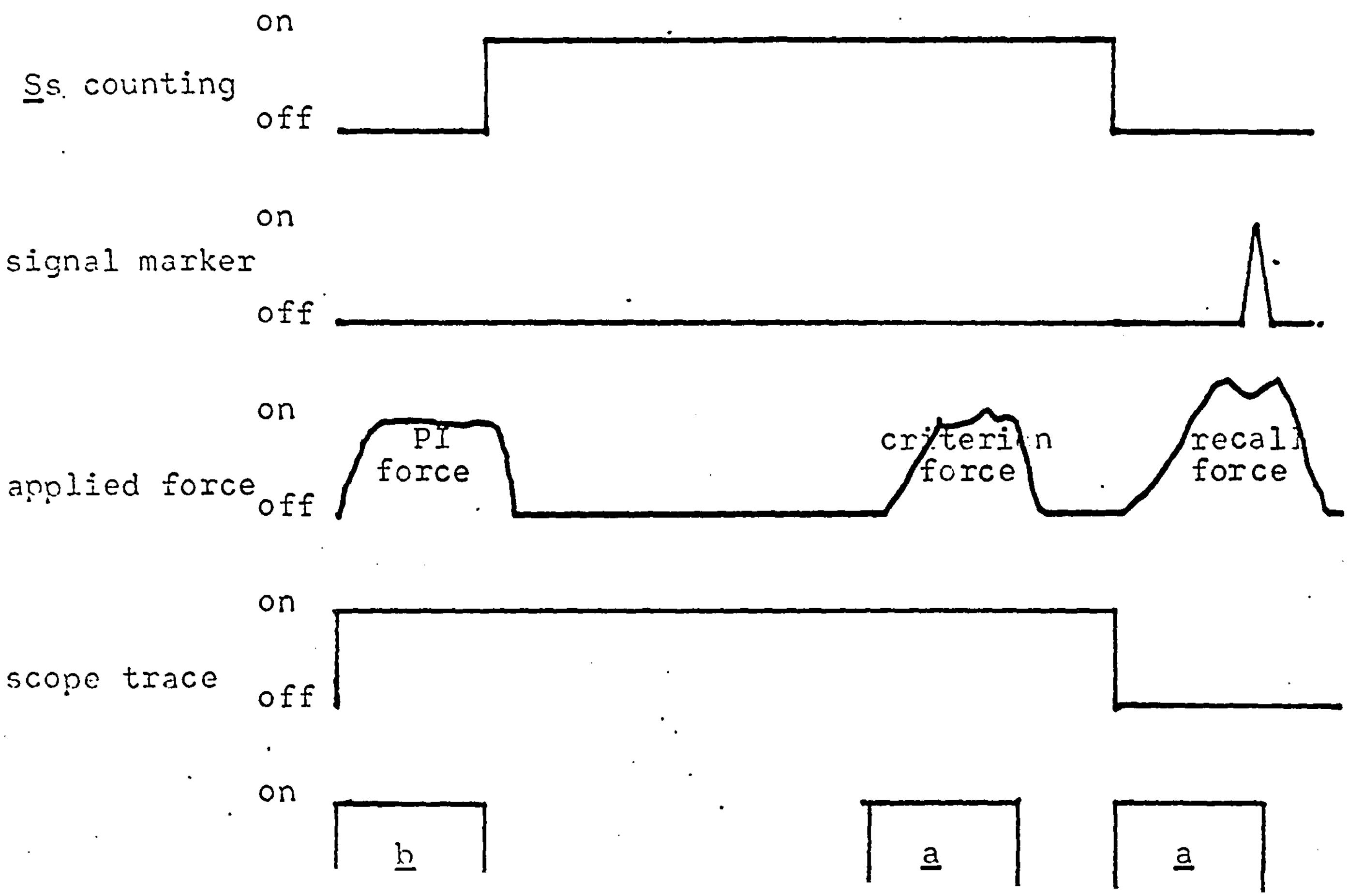
The identical apparatus as described in Experiments I, II, and III was used.

Experimental Design

The identical experimental design as reported in the RI design of Experiment III was employed with the exception that the additional forces and control conditions occurred *prior* to application of the criterion force, representing therefore a PI design.

Procedure

Identical procedures to those of Experiment III were used, with the exception of a change in Subjects Instructions (Appendix 4). Thus, the Ss were required to make a visually-guided force response prior to production of the criterion force. The Ss were informed that the second of the two force applications would be tested later. The prior force was either greater or of lesser magnitude than the criterion force. In half the trials, the condition of 'zero' force occurred prior to the criterion force. This was signalled by onset of a zero digit on the digital display. In half of these zero trials, S was instructed to count backwards by threes from a number read over the intercom by E simultaneous with presentation of the digit zero. The backwards counting was terminated when the criterion force digit appeared. On the remaining half of these zero trials, S merely sat passively until the criterion force was signalled by onset of a second digit. In all cases, in response to the second digit, S made a visually-guided force application to the indicated level. Four seconds after offset of this second digit, the same digit reappeared and S attempted to recall the criterion force, in the same manner as in previous experiments. Thus, all trials had the same unfilled, four-second retention interval between completion of the criterion force application and the subsequent recall test. Figure 13 provides a time line of the events occurring in this experiment.


on
Ss. counting
off
on
signal marker
off
on
PI
force
criterion
force
recall
force
applied force
off
on
scope trace
off
on
b
a
a

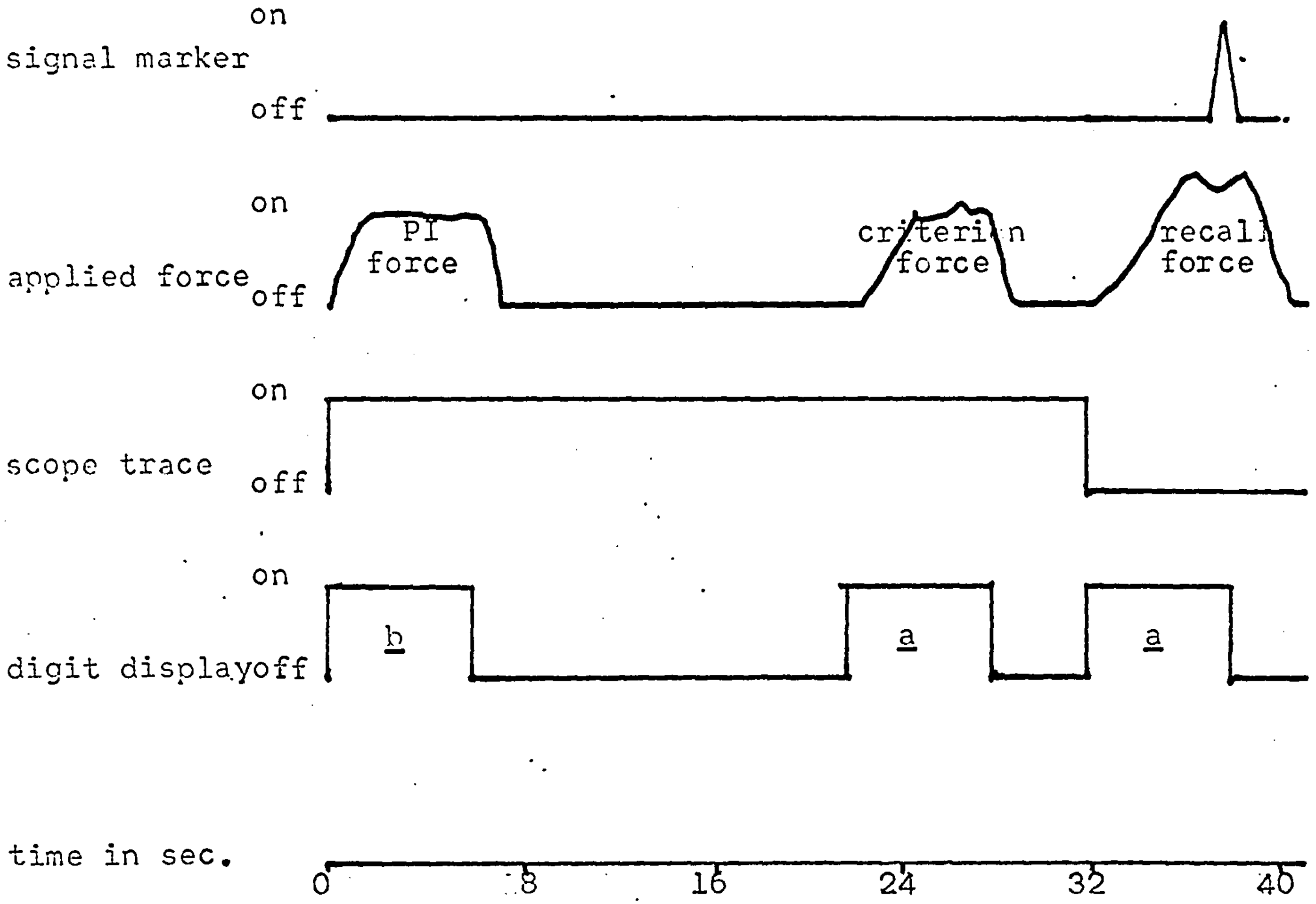


Fig. 13. Time-line of Events Occurring in Experiment IV. Criterion-force digit indicated by a, proactive by b.

Results

The Ss performance was recorded as in the previous experiments. Table 9 provides a summary of the means for all of the variables under consideration. The variables of major interest in this experiment are the prior-force relative direction (similarity) and prior-force relative magnitude. It can be seen in Table 9 that the effects of similarity are minor, while the effects of the prior force applications are relatively strong. Table 10 presents the results of an analysis of variance performed on both the absolute and the algebraic errors. As in the previous RI experiment, this analysis considers only trials on which a PI force was produced. The effects of application of a prior force on the subsequent recall of the criterion-force was significant for both error analyses, but prior-force similarity was not. In the algebraic error analysis, the interaction of criterion-force direction by prior-force relative magnitude was significant, as were the criterion-force level by prior-force relative direction by prior-force relative magnitude interactions. These relationships are presented in Figure 14 through 16. Figure 14 shows that Up criterion-forces were more sensitive to the relative magnitude variable than were Down forces, though the direction of effect was the same in both cases. Figure 15 shows force 4 to be somewhat more influenced by the relative magnitude variable than was force 2. Finally, Figure 16 shows a reversal effect. Prior forces applied in the same direction as the criterion force result in a somewhat lesser

Table 9

Mean Absolute and Algebraic Errors in Millimeters For All Levels of Task Direction, Force, Task Similarity, and Prior Activity

Direction	
Up	Down
5.66 (5.25)	5.29 (4.86)

Force	
2	4
5.86 (5.73)	5.09 (4.37)

Prior Force Relative Direction (Task Similarity)	
Same	Opposite
5.50 (5.07)	5.44 (5.04)

Prior Force Relative Magnitude			
Greater	Count	Sit	Lesser
5.86 (5.51)	5.73 (5.22)	5.53 (4.90)	4.84 (4.43)

NOTE--Algebraic Errors are in Parenthesis

Table 10

Analysis of Variance of Absolute and Algebraic Errors of Proactive Interference Study

		Absolute			Algebraic		
Source	df	MS	F	p	MS	F	p
Ss	23	108.77			139.24		
Up-Down (A)	1	36.38	3.83		14.18	0.60	
Ss x A	23	9.50			23.44		
Force (B)	1	0.14	0.01		36.14	1.86	
Ss x B	23	10.34			19.40		
Task Similarity(C)	1	13.42	2.64		13.58	2.12	
Ss x C	23	5.08			6.41		
Greater-Less (D)	1	99.02	12.57	.01	115.50	11.89	.01
Ss x D	23	7.88			9.63		
A x B	1	22.52	2.93		7.21	0.71	
Ss x AB	23	7.68			10.16		
A x C	1	0.04	0.01		0.06	0.01	
Ss x AC	23	7.55			7.94		
A x D	1	35.65	3.99		47.18	5.75	.05
Ss x AD	23	8.93			8.20		
B x C	1	13.58	1.69		27.20	3.17	
Ss x BC	23	8.02			8.57		
B x D	1	11.83	2.94		19.35	4.41	.05
Ss x BD	23	4.02			4.39		
C x D	1	39.40	3.10		73.32	9.47	.01
Ss x CD	23				7.74		
A x B x C	1	1.73	0.22		3.26	0.51	
Ss x ABC	23	7.90			6.36		
A x B x D	1	3.41	0.40		5.85	0.58	
Ss x ABD	23	8.54			10.17		
A x C x D	1	12.83	1.03		23.31	2.22	
Ss x ACD	23	12.44			10.52		
B x C x D	1	3.19	0.35		3.72	0.26	
Ss x BCD	23	9.20			14.33		
A x B x C x D	1	41.21	5.07	.05	71.93	5.99	.05
Ss x ABCD	23	8.13			12.01		

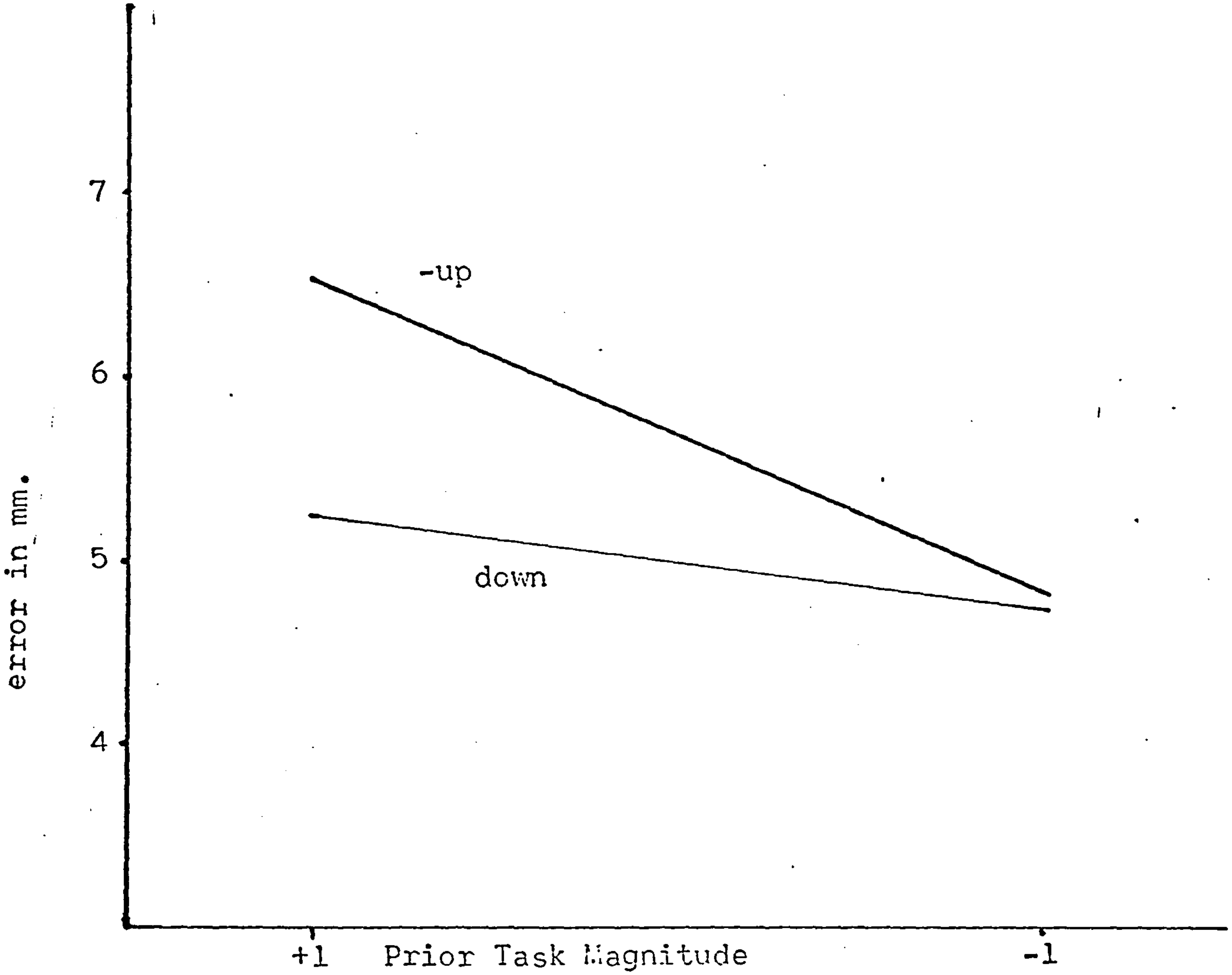


Fig. 14. Mean Algebraic Error of Up-Down Responses as a Function of Prior Task Relative Magnitude.

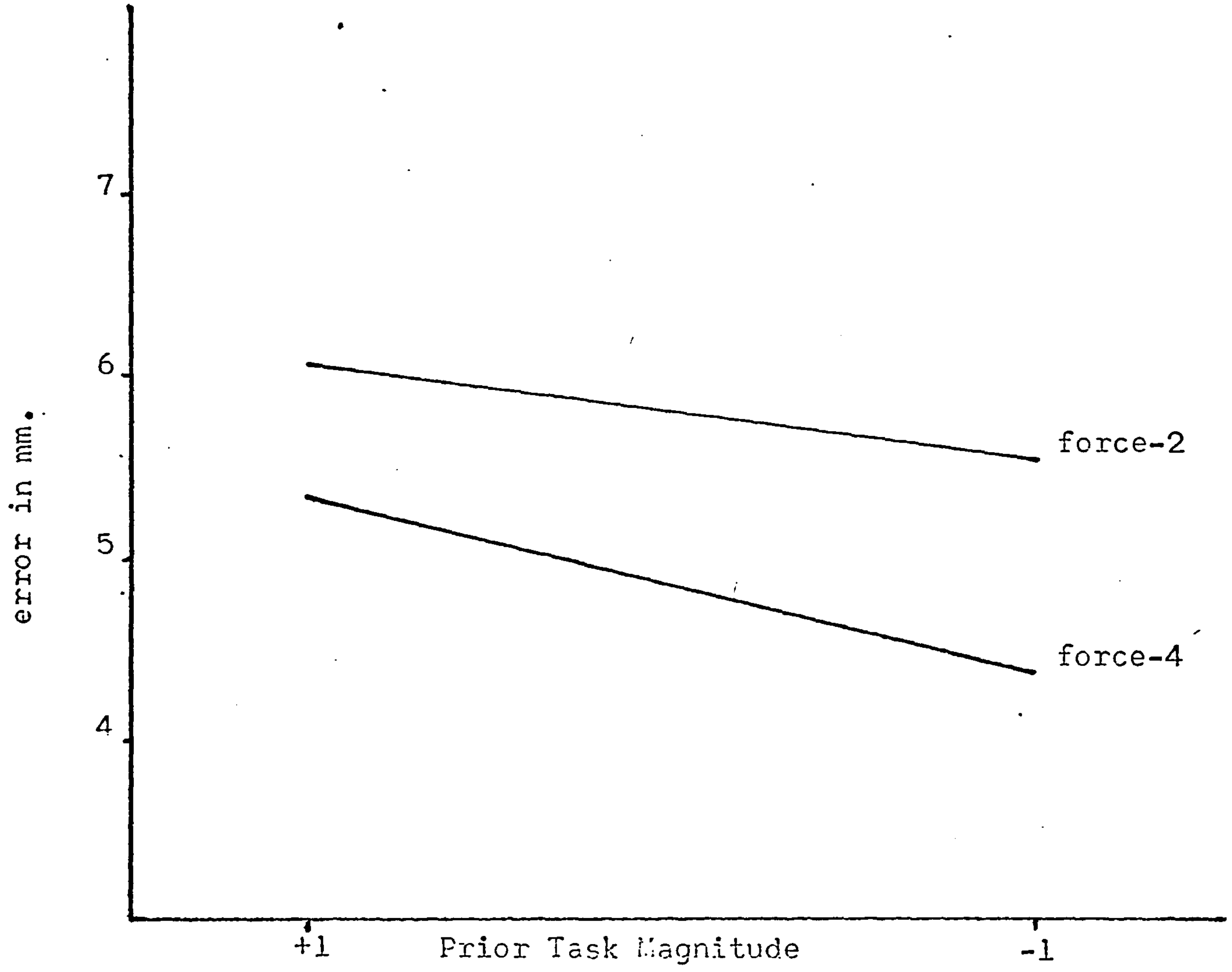


Fig. 15. Mean Algebraic Error of Force Task as a Function of Prior Task Relative Magnitude.

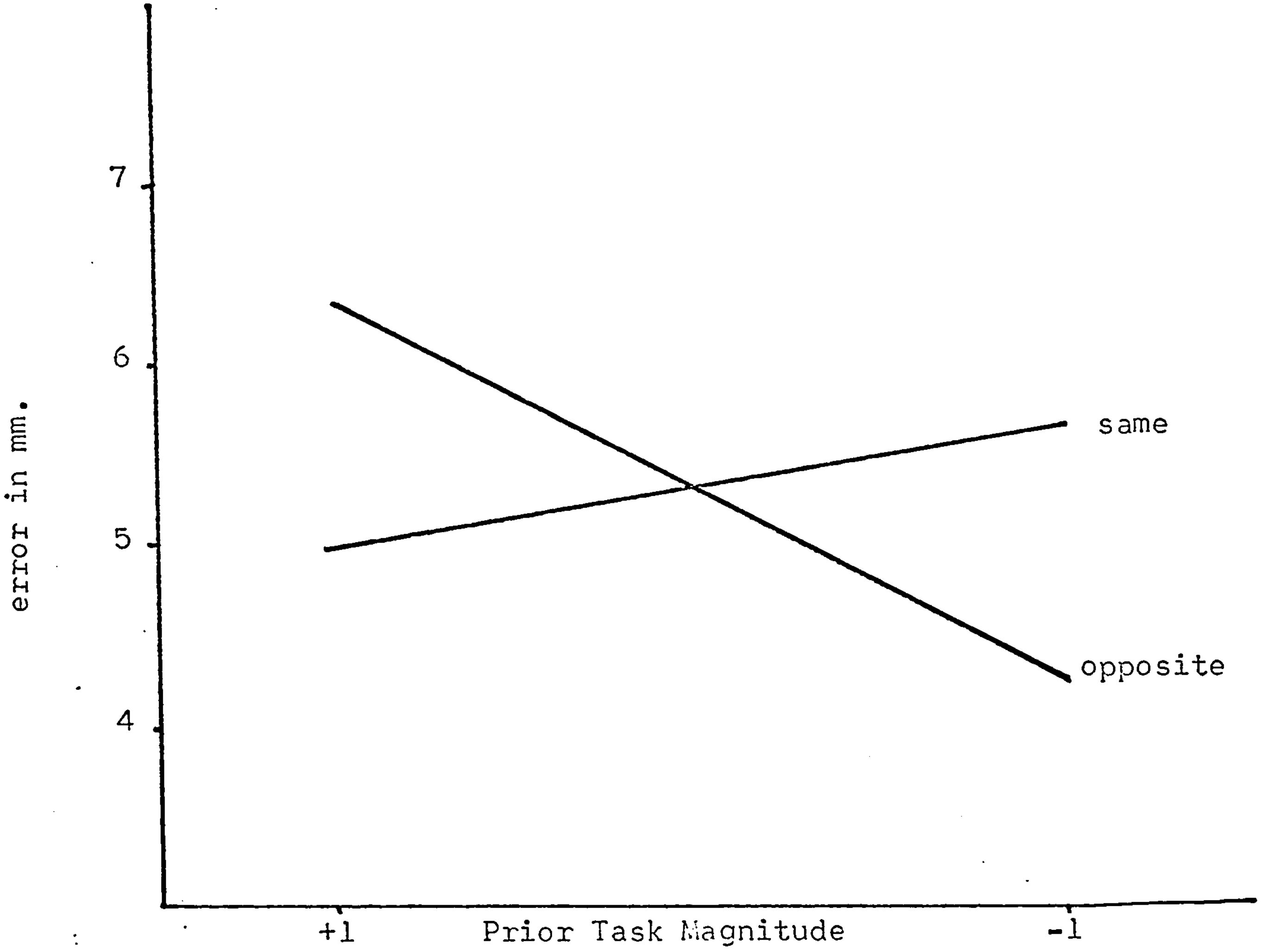


Fig. 16. Mean Algebraic Error of Prior Task Magnitude and Task Similarity Relationships.

error if associated with greater relative-magnitudes. A very strong reverse effect is noted for the opposite dimension, however. A presentation of the four-way interaction noted in Table 10 will not be given.

As in the previous study, an analysis of the significance of the differences between all levels of the prior activity, including the control conditions, was accomplished by use of a Neuman-Keuls test following an overall analysis of variance. The overall analysis yielded $\underline{F}$s $(3, 46) \leq 4.77$, $p > .01$. None of the comparisons for the Neuman-Keuls procedure reached statistical significance (Table 11) for either the absolute or the algebraic error analyses.

Table 11

Comparison of Prior Tasks Mean Absolute and Algebraic Errors Using Neuman-Keuls Test

	Greater	Control	Sit	Lesser
Greater		0.39 (0.83)	1.00 (1.74)	3.09 (3.11)
Control			0.61 (0.91)	2.70 (2.26)
Sit				2.09 (1.34)
Lesser				

Note: $p < .05 = 3.74 =$ *

$p < .01 = 4.60 =$ **

Discussion

The conditions of RI in the preceeding study resulted in large decrements in recall performance. The basis for the obtained decrements were related systematically to the relative magnitude of the force tasks which occurred during the retention interval. In addition, a counting activity interpolated in the retention interval also was effective in reducing recall performance. Thus, RI was found to play a significant role in motor STM.

The results of the present experiment indicate that when a force application is required immediately preceding the criterion force, Ss subsequent recall performance suffers significantly. Thus, with forces which are of greater magnitude required prior to the criterion force application, the recall errors increase, as compared to the case when a force of lesser magnitude than the criterion force is required.

Interference theory might account for these results as in the discussion given in the RI experiment. The trace left by the prior force application interacts with the criterion trace and a 'net' trace, representing perhaps the mean magnitude is the end result. Recall forces are then matched against this transformed trace rather than against the criterion trace. The relative magnitudes of RI and PI effects cannot be directly compared in the present studies, since the time lines of Figures 9 and 13 show that the retention intervals were not equal across studies. It should be noted that the present paper was interested in demonstrating the phenomena of interference in motor STM, rather than in a strict comparison of PI and RI. The relatively weaker PI effects may well be due to the shorter retention interval intrinsic to the PI study.

Generally, it can be said that requiring S to produce a force prior to a criterion force results in increased error at recall. Requiring S to count backwards, however, had relatively little effect on subsequent recall.

CHAPTER VII

STUDY OF MOTOR SHORT-TERM MEMORY V. EFFECTS OF PRACTICE

The following two experiments are concerned with the effects of repetition of the criterion force upon the subsequent recall of that force. Repetition of the criterion movement led to significantly better performance on the subsequent recall task in the Adams and Dijkstra (1966) study, hence they concluded that motor STM operated in a similar manner to verbal STM. As previously indicated, the positioning task used by Adams and Dijkstra was characterized by an undershooting response set. To what extent was this response set a determiner of their results? What effect did this phenomena have upon their conclusions? The following studies seek an answer to these questions by examining the manner in which practice operates when the characteristic response set is one of overshooting.

Experiment A

Method

<u>Subjects</u>

Twenty-seven University of Hawaii undergraduate volunteers from an introductory psychology class participated for course credit. They had not previously served in any of the prior memory experiments. Three males and six females were assigned to each of three groups. This assignment was random under the constraint that an equal number of males and females be repeated in each group.

Apparatus

The same experimental apparatus as described in Experiment I was used, along with the subsequent additions described in Experiment II.

Experimental Design

A three-way mixed model was employed with three levels of repetition of the criterion force (1, 3, and 7 repetitions) as the between-Ss variable, and two levels of force direction (Up-Down) and three levels of force magnitude (1, 2, 3) as the within-Ss variables. Within each group, each S received all combinations of Up and Down force directions paired with the three force magnitudes. This yielded six unique trials per S. The order of Up followed by Down was balanced such that down-up occurred equally often in each group as up-down. Thus the order of presentation was completely counterbalanced, as was the presentation of the force magnitudes.

Procedure

Identical procedures to those of the preceding experiments were used, with the exception of the changes in Subjects Instructions for each group as noted in Appendix 5. Thus, Ss in group R-1 were required to apply the criterion force once, then sit quietly during the twenty-second retention interval, until signalled to repeat the criterion force without visual-guidance. The Ss in group R-3 were required to repeat the visually-guided force application three times, once each time the digit stimulus was presented, then wait quietly during the retention interval. The Ss in R-7 were treated identically to those in group R-3, except they had to repeat the criterion force seven times prior to the retention interval. The retention interval was 20 seconds for all groups. Figure 17 shows a time line of the Ss responses for all three groups. The inter-trial interval was 30 seconds.

Results

The performance of the three groups was recorded as in previous experiments. Table 12 provides a summary of the means for the three variables under investigation. It can be seen that the variable of major interest, practice, appears to have had an anomalous effect. Increasing repetitions resulted in larger errors. The effect of the force levels appears large, with larger forces associated with larger error scores. Table 13 presents the results of an analysis of variance for both the absolute and the algebraic errors. The main effect of Force was significant for the absolute errors, but all other effects failed to reach statistical significance.

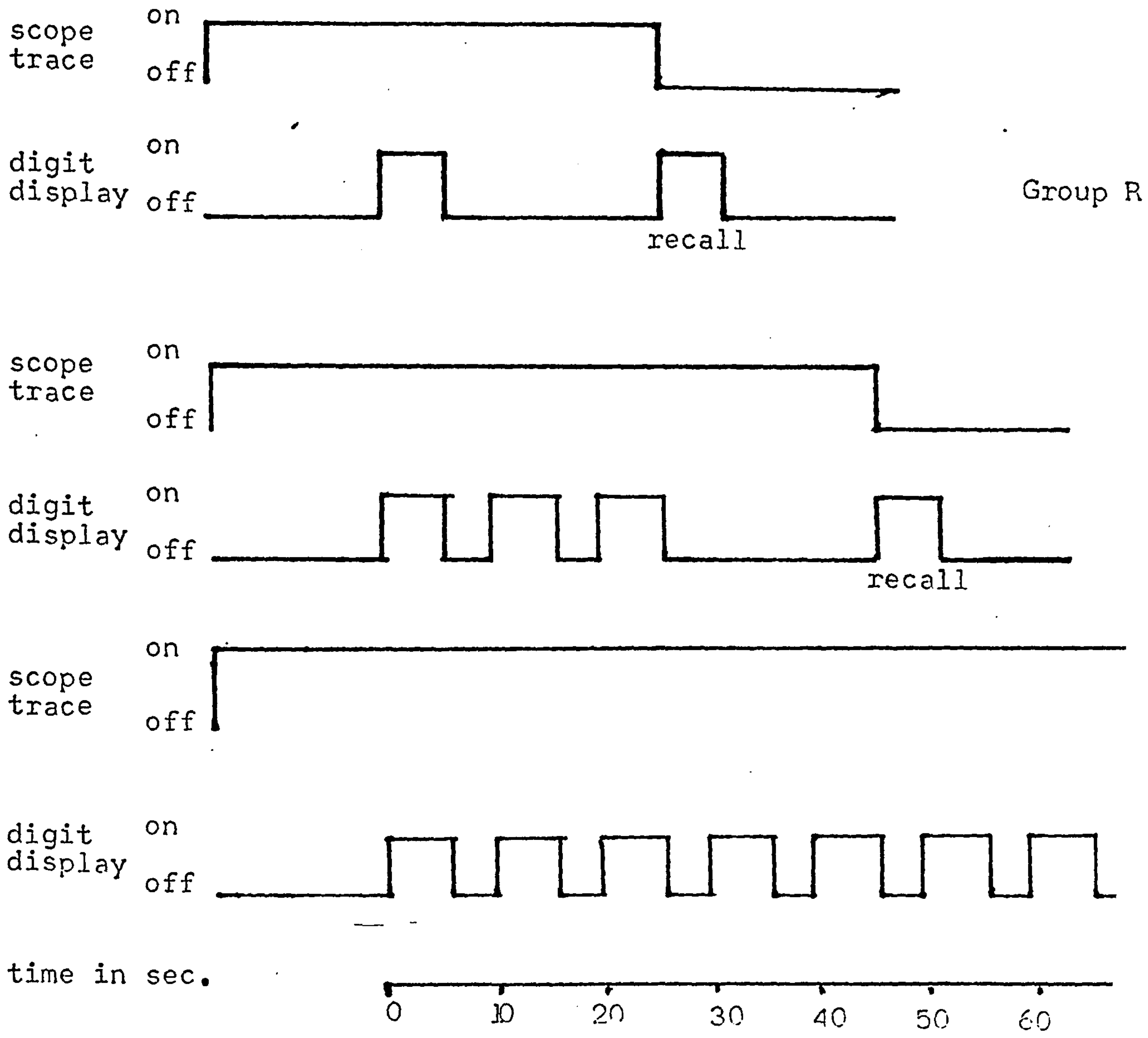


Fig. 17. Time-line of Events Occurring in Experiment

Table 12

Mean Absolute and Algebraic Errors for All Levels of Task Direction, Force, and Repetition

	Direction	
Up		Down
3.97 (3.01)		4.00 (2.90)
	Force	
1	2	3
3.07 (2.49)	4.03 (3.21)	4.85 (3.18)
	Repetition	
1	3	7
2.96 (2.12)	4.39 (3.10)	4.59 (3.67)

NOTE--Algebraic Errors are in Parenthesis

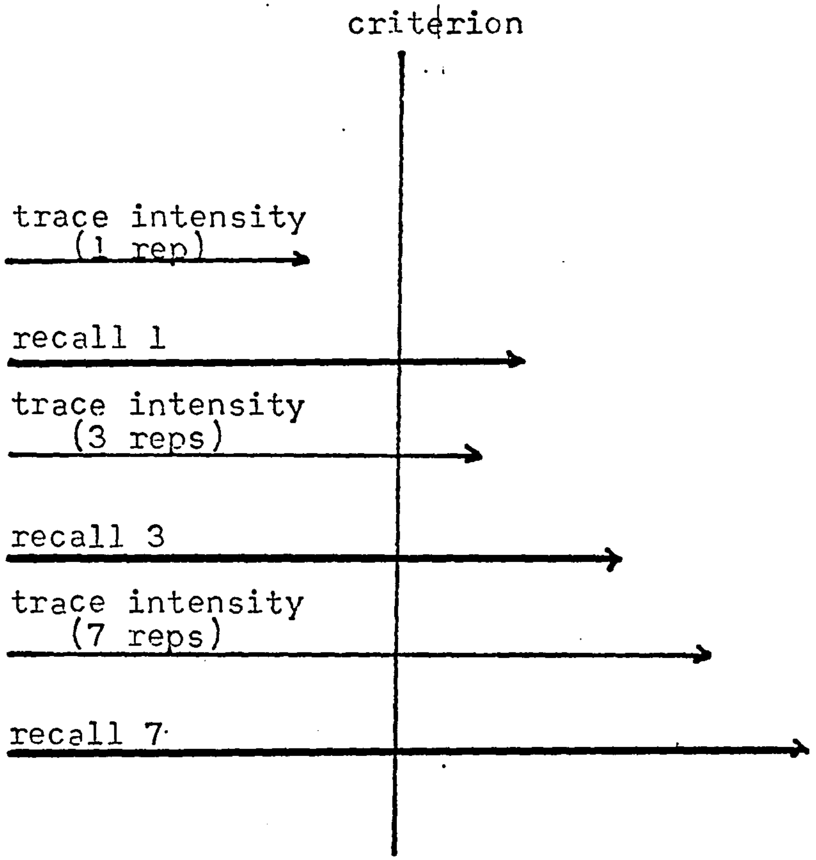
Table 13

Analysis of Variance of Absolute and Algebraic Errors of Unfilled Repetition: Experiment A

Source	df	MS	F	p	MS	F	p
Between Ss	26						
Repetition (A)	2	42.57	1.65		33.10	0.60	
Ss	24	25.79			55.01		
Within Ss	135						
Up-Down (B)	1	0.03	0.00		0.42	0.03	
A x B	2	0.31	0.03		8.26	0.60	
B x Ss	24	11.71			13.67		
Force (C)	2	43.01	5.96	.01	8.87	1.00	
A x C	4	3.61	0.50		19.25	2.17	
C x Ss	48	7.22			8.89		
B x C	2	2.88	0.39		0.69	0.07	
A x B x C	4	2.49	0.34		10.08	0.97	
BC x Ss	48	7.37			10.42		
Total	161						

Discussion

In the present experiment, the main effects of repetition were not statistically significant. However, a trend is clearly present in the means shown in Table 12. With repetition, performance appears to deteriorate. Since this is directly contradictory to the findings of Adams and Dijkstra, and since it is clearly at odds with expectations from reinforcement theory generally, these data might be immediately dismissed. Before doing so however, a careful consideration of the nature of the present force task is in order. Table 12 bears out the fact once again that the primary response set during recall was one of overshooting the criterion force. This overshooting increased with larger force responses, but of even more interest, it increased after several repetitions of the force task. Note that the postulated effect of reinforcement or repetition by most theoretical positions can be considered to function through the strengthening of the memory trace. Thus, in the present case, successive repetition is postulated to lead to a stronger or more intense trace. Given a characteristic overshooting response set, the more intense traces should result in greater errors--a process similar to that hypothesized in Experiment II to account for effects of the interpolated activity of counting backwards. Figure 18 shows the postulated relationships of trace intensity building up with repetition. The errors build up also, as in each case the recall force overshoots the trace representing the criterion


criterion
trace intensity (1 rep)
recall 1
trace intensity (3 reps)
recall 3
trace intensity (7 reps)
recall 7

force. It can be seen that this process would result in an apparent increase in error with repetitions.

The between-Ss design used to assess the effect of repetitions is not particularly sensitive. Given this design and the small number of Ss used per group (nine), it is possible that a type II error has occurred with respect to the detection of a significant effect of repetition. Since there has been established a theoretical basis for supposing that successive repetition will lead to increased errors, given an overshooting response set, it would be worthwhile to conduct a more sensitive test of the effects of this variable. Experiment B will again test for effects of repetition, but repetition will be tested as a within-Ss variable. In addition, to control activity (rehearsal opportunity?) during the retention interval, Ss will be required to count backwards rather than merely sit.

Experiment B

Method

Subjects

Twelve University of Hawaii undergraduate volunteers from an introductory psychology course participated for class credit. There were eight males and four females, none of whom had previously served in a memory experiment.

Apparatus

The same experimental apparatus as described in Experiment A was used.

Experimental Design

A mixed design was employed, with the between-Ss variable being the assignment of Up and Down directions paired either with one or seven repetitions. Thus, there were two repetition levels used, either one or seven repetitions. For half the Ss, Repetition -1 was applied only in the Up direction and Repetition-7 only in the Down direction (U1-D7), and for the remaining Ss, the reverse was true (U7-D1). There were three force levels used (Forces 1, 2, and 3) and so, for example, for Group U1-D7, these forces were applied once in the Up direction and seven times in the Down direction. Thus, the three levels of force and the two levels of repetition were the within-Ss variables. The sequence of Up-Down was completely counterbalanced, as was the presentation of the force levels. Each S received a total of six unique criterion forces during the experiment.

Procedure

Identical procedures to those of the preceding experiment were used, with the exception of the change in Subjects Instructions as noted in Appendix 6. In addition, Ss were required to count backwards by three's during the retention interval, beginning from a three digit number presented by E over the intercom. The counting backward was paced by an auditory pulse as described in Experiment II. The retention interval was the same twenty-second duration as in the preceding Experiment A.

Results

Performance of the Ss was recorded as in previous experiments. Table 14 provides a summary of the means for the three variables under investigation. Again force appears to show a large effect, with larger force levels associated with larger errors. The variable of major interest, the effects of successive repetition also appears considerable, with larger errors associated with the greater number of repetitions. Note that this effect is identical to the trend noted in Experiment A.

Table 15 presents an analysis of variance performed on both the absolute and algebraic errors. It can be seen that the effects of repetition was highly significant for both error analyses, and that force was significant for the algebraic analysis. The interaction of Groups and repetition is not considered of importance since in this case, the Groups are actually only a control for any interaction of force and direction of movement.

Discussion

The effect of repetition or practice has clearly resulted in poorer performance in the present study, confirming the trend noted in Experiment A. The design of the present study is considered superior to that of Experiment A in that it controlled better for individual differences, and in addition, by using fewer trials than Experiment A, reduced possible fatigue effects. The opportunity for rehearsal was

Table 14

Mean Absolute and Algebraic Errors in Millimeters For All Levels of Task Direction, Force, and Repetition

Direction

Up (1)-Down (7)	Up (7)-Down (1)
6.90 (6.85)	7.73 (7.41)

Force

1	2	3
4.35 (4.25)	6.81 (6.81)	10.79 (10.33)

Repetition

1	7
6.50 (6.14)	8.13 (8.12)

NOTE--Algebraic Errors are in Parenthesis

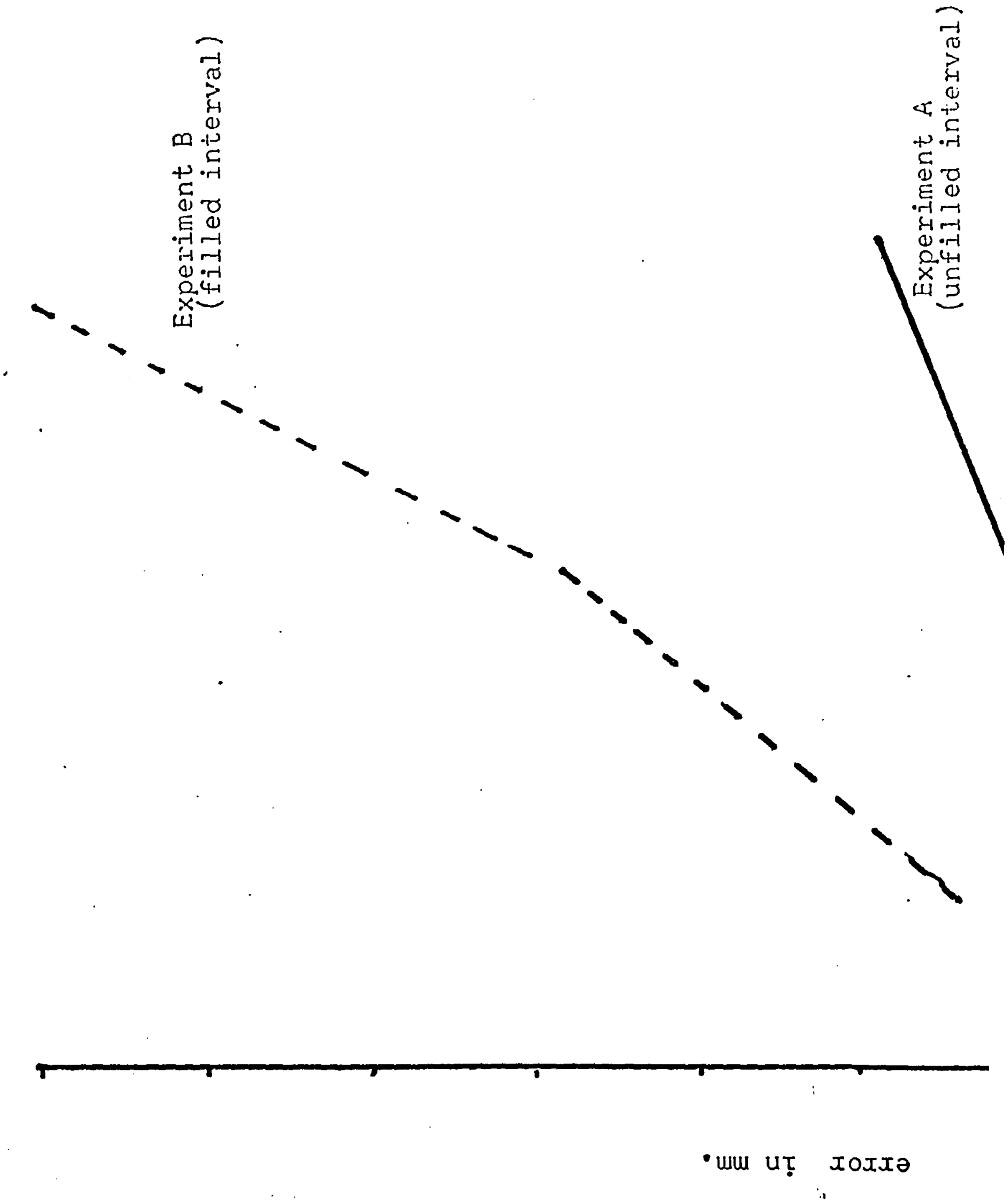
Table 15

Analysis of Variance of Absolute and Algebraic Errors for Filled Repetitions

		Absolute			Algebraic		
Source	df	MS	F	p	MS	F	p
Between Ss	11						
U1D7-U7D1 (A)	1	8.82	0.13		5.78	0.10	
Ss	10	70.42			59.35		
Within Ss	60						
Repetition (B)	1	116.54	7.33	.05	70.41	11.06	.01
A x B	1	2.57	0.16		37.27	5.85	.05
B x Ss	10	15.90			6.37		
Force (C)	2	42.69	1.99		223.30	16.26	.001
A x C	2	0.24	0.01		21.62	1.57	
C x Ss	20	21.46			13.73		
B x C	2	7.94	0.95		26.13	2.21	
A x B x C	2	19.85	2.37		25.11	2.13	
BC x Ss	20	8.35			11.80		
Total	71						

carefully controlled as well, by the introduction of a counting-backwards task interpolated during the retention interval. It can be seen in Figure 17 that the overall effect of the counting task was to increase rather markedly the overshooting associated with each force level, a finding consistent with previous results given in Experiment II. It was suggested in the discussion of Experiment II that a possible source for this effect of counting-backwards can be explained by reference to a state of increased, generalized muscle tension produced by the counting activity, which interacts with the stored memory trace of the original criterion force. Thus, the muscle tension associated with this counting activity appears to add or summate with the existing criterion force trace.

A strengthening or intensification of the criterion-force trace was postulated to account for the anomalous effect of repetitions in Experiment A (Figure 18). The assumptions were that repetition acts to intensify the memory trace, and that during the recall test the characteristic overshooting response set is made with respect to the intensified trace, resulting in an apparent increase in errors with trace intensification, i.e., with repetitions. This viewpoint appears reasonable to account for the present results as well. The process occurring during the recall trial can be viewed as a trace-comparison mechanism, in which the internal representative (trace) of the stimulus is compared with the ongoing kinesthetic stimulation.


Experiment B
(filled interval)
Experiment A
(unfilled interval)
error in mm.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

Experiment I investigated recall of a criterion force as a function of time. Retention intervals ranged from 4 to 60 seconds, and were unfilled, S merely sitting passively until the signal for recall occurred. The finding of major importance was that forgetting was not observed to increase as a function of time. Reproduction of the criterion force appeared to remain unaffected by time, and perhaps even to show some improvement. Also discovered was the dominant tendency for Ss to overshoot the criterion force during recall, regardless of the levels of the other variables present in the experiment.

Experiment II sought to determine whether the opportunity for rehearsal inherent in the unfilled retention intervals of Experiment I was responsible for the apparent lack of forgetting noted in that experiment. Prior motor-STM experiments by other investigators had noted, though, that rehearsal opportunity was not a significant variable in the retention of kinesthetically-based tasks. A counting-backwards activity was used in Experiment II to prevent any rehearsal of the criterion force during the retention interval, and forgetting under this condition was compared with that obtained when S remained passive during the retention interval. The results again indicated that the forgetting function did not conform in a simple way to time or to predictions based on a concept of rehearsal. Indeed, a significant improvement in recall was demonstrated over the time intervals employed (4 to 30 seconds) a finding completely opposite to previously reported results of other investigators, but supportive of the trends noted in Experiment I. The counting-backwards condition was found to produce a relatively constant decrement in recall over the passive condition, for all retention intervals. An analysis of the response-set characteristics noted in a variety of other types of motor tasks by other investigators provided some insights into the present findings. It was noted that tasks which require a linear-positioning movement, and tasks which require location of an object in space, and which involve movements of greater extent than five centimeters, have all been reported to be associated with underestimations or undershooting of the criterion movement. Additionally, tasks requiring force applications exceeding twenty pounds are also characterized by undershooting. Force applications of less than twenty pounds, however, are generally associated with overshooting, as are positioning tasks of less than five centimeters. The Adams and Dijkstra (1966) linear-positioning task was characterized by undershooting, a finding consistent with other research which has used similar linear-positioning tasks. The tasks reported by Posner (1967) and Posner and Konick (1966b) were characterized by undershooting, a typical result for location and displacement tasks. While Poser and

Konick and Posner actually did not report the algebraic errors obtained on their tasks, a recent personal communication with Posner confirmed that his tasks were characterized by an undershooting response set. Additionally, in an unpublished study of the present writer, an angular-positioning task similar to that used by Posner was studied, and undershooting was found to be the most characteristic response of the _S_s.

Given that both the Adams and the Posner studies were characterized by undershooting, and that the present study was characterized by overshooting, how might this account for the contradictory findings with respect to forgetting as a function of time? It is generally accepted by memory theorists that some component of the stimulus situation is extracted by the organism and stored for later use. In addition, for decay theorists, a weakening of the stored trace occurs as the retention interval increases, given that rehearsal is precluded. In any event, subsequent reproduction of the motor task during the recall test is accomplished by relating the stored trace of the criterion force to the ongoing kinesthetic or proprioceptive stimulation of the recall task. Thus, if the response set of the organism for any particular task is one of undershooting, as in the Adams and the Posner studies, weakening of the trace will result in an apparent decrease in accuracy over the retention interval, since the recall force departs more and more from the criterion force. Large, negative algebraic errors should be observed. However, if the organism is set to respond with overshooting, the weakening of the trace over the retention interval will result in an apparent increase in accuracy. This is because as S overshoots a weakening trace, he begins to approach the criterion force rather than depart from it. The observed increase in errors as a function of the counting-backwards task was explained through the assumption that a generalized muscle-tension state occurs in this task, and that the effect of such a state is an intensification of the criterion trace. Hence, S overshoots a strengthened trace, and his apparent error increases. At this point it is clear that a fading trace theory combined with a consideration of task-specific response sets can account for the seemingly disparate results of the present and past studies.

Experiment III sought to determine the nature of interference effects observed in a RI paradigm. Directional similarity of an interpolated force to the criterion force (same or opposite direction), and the relative magnitude of the interpolated force (greater than or less than the criterion force) were the variables of primary interest. The findings indicate that criterion-force recall was susceptible to interference, not as a function of the similarity variable, but as a function of the relative-magnitude variable. Interpolated forces of greater magnitude than the criterion force produced larger recall errors than did interpolated forces of smaller magnitude. The recall force appeared to be a compromise between or averaging of the criterion force and the interpolated force.

The findings of Experiment III were interpreted in terms of interference theory. The interpolated-force trace was postulated to interact with the stored trace of the criterion force, a process similar to what has been termed 'assimilation' in past research (Woodworth and Schlosberg, 1954). The basis of this assimilation was seen to operate bi-directionally, along the dimension of relative-force magnitude or intensity, with the recall force biased in the direction of the relative magnitude of the interpolated force. As in Experiments I and II, the characteristic overshooting response set was again noted in the present experiment. In addition, control trials corroborated the results of Experiment II, with respect to the finding of significantly greater errors associated with the counting-backwards task, as compared to merely sitting passively during the retention interval.

Experiment IV investigated the effects of prior force applications on recall of a subsequent criterion force. The variables used were the same as in Experiment III and demonstrated that prior motor tasks were effective in creating forgetting. A significant effect of the greater magnitude force as compared to the lesser magnitude force was found with the same directional-biasing characteristics as observed in the RI study. An interpretation in terms of interference theory was again given.

Experiment V examined the effect of repetition of the criterion force on subsequent recall performance. The experiment was conducted in two parts, representing between-*Ss* and within-*Ss* experimental designs. The number of repetitions of the criterion force varied from one through seven. The apparent anomalous finding for both parts of the experiment was that performance suffered as a result of the repetition of the criterion force, with greater errors associated with more repetitions. A consideration of the response set of overshooting, which again characterized the recall of the criterion force, revealed that overshooting increased with successive repetitions of the criterion force. The increase in errors as a result of the increased overshooting induced by repetition of the criterion force was seen to be consistent with interference theory, in which traces are assumed to interact. It was suggested that repetition acts to intensify the trace of the criterion force, with each successive repetition adding an increment of intensification. During recall, the overshooting response is made with respect to the intensified trace, resulting in the observed increase in errors, or apparent forgetting. Interference theory, coupled with a consideration of the response set of overshooting, was thus able to account for the contradictory results.

Conclusions

The present series of investigations do not provide direct evidence for forgetting of an applied force, for retention intervals of up to 60 seconds. Previous experiments of motor-STM which have reported typical forgetting functions over time have used tasks which were characterized by undershooting response sets, whereas the present study was characterized by an overshooting response set. Thus, it is argued that the 'apparent' forgetting reported by these prior studies must be evaluated against their task-related response set of undershooting. In the present study, it is suggested that the findings of an 'apparent' improvement in recall is associated with this same factor of response set, only in this case, an overshooting response set was involved. The evidence for forgetting obtained in the prior studies, and the improvement in recall performance noted in the present study may thus appear irreconcilable. Nevertheless, the disparate findings are seen to converge on the concept of a fading memory trace with time. That is, the assumption that the trace of the criterion force decays in intensity autonomously with time, coupled with a given type of response set, can explain both an apparent increase in error (undershooting response set) or an apparent decrease in error (overshooting response set) with time.

Interference effects in motor STM have been demonstrated conclusively in the present paper, in both the PI and RI studies. The relative magnitude of the interferring force to the criterion force is postulated to occur along an 'intensive' dimension; the trace of the interpolated or prior force is also stored on this same dimension and interacts with the trace of the criterion force. This interaction is termed directional-biasing, and conceptually, results in a mean trace or perhaps, a weighted-mean trace at retrieval (the weighting would represent recency effects, with the last-stored trace having a relatively larger influence). The Ss recall force is made with reference to this mean trace, rather than to the criterion trace.

A more general type of trace interference is also postulated to occur, however, when general activity is required of the S during the retention interval. Thus, the demonstration of increased recall error as a result of an interpolated counting-backwards task is due to the intensification of the criterion memory trace through interaction with proprioceptive or kinesthetic components of the generalized muscle-tension state produced by the activity.

To provide a full account of the findings of the studies presented in the present paper, a dual process theory of motor STM is thus proposed. This theory consists of the fading trace concept, which assumes that traces decay autonomously over time unless strengthened by repetition or rehearsal, and the interference concept, which assumes an interaction between events occurring either prior to or immediately following the event to be recalled.

As indicated, trace decay is seen to occur with respect to the intensive dimension of the stimulus. Studies in verbal STM have been focused largely on the acoustic dimension, but as Hintzman (1967) has shown, the dimensions involving storage, coding, and interference are far from clarified, and may have motor components. It is possible that the intensive dimension is relevant for these verbal studies as well. In addition to this line of reasoning, and perhaps of greater importance, is the fact that while acoustic information has a large sensory component, it is still primarily symbolic. This apparently is not the case with kinesthetic information. It is concluded that information which cannot be symbolized, cannot be rehearsed. In this sense, then, the conclusions of the writer are consistent with those of Posner (1967) and Adams (1967). Kinesthetic information is coded differently than verbal or symbolic information.

The dual-process theory proposed in the present paper is similar to the theories of Wickelgren (1966) and Posner and Konick (1966a). All three employ a two-factor process to account for the phenomena of forgetting, and all three propose the same basis factors, i.e., decay and interference. The Wickelgren theory states that the decay factor operates as a reduction over time in the strength of the associations between the internal representative of the acoustic cue (sound of ē or ê) and the internal representative of the stimulus (the letter 'b' for example). This results in reduced discriminability during retrieval. Interference in the Wickelgren theory refers to the competing associations established between the cue representative and the representative in nearby letters of the PI and RI lists. The Posner-Konick acid-bath model proposed to account for their findings in verbal-STM involves both a trace-decay process (unspecified) and an active interaction of the stored traces during the retention interval. Thus, both the time in store, and the similarity (on acoustic dimensions) of the stored items are determiners of forgetting.

The present theory is seen to be most consistent with the Posner-Konick theory. In particular, it would seem compatible given the qualification that trace-decay and trace interference in motor-STM occur on an intensive dimension. Motor-STM is seen to differ rather basically from verbal-STM in that the type of coding used (type of trace) is quite different. The implication of such a conclusion is this: Covert, symbolic rehearsal cannot be accomplished with a motor task.

In summary, the basic differences seen to exist with respect to verbal and motor-STM are in terms of (*a*) symbolic processes occurring in verbal but not in motor interference on an intensive dimension for motor information, while for verbal information, the trace decays in strength on an unspecified dimension, and interference occurs on an acoustic dimension.

In spite of the differences mentioned above, the generality of the laws of forgetting in STM are seen to hold for both verbal and motor findings. Thus, decay factors and interference factors must be invoked to account for either body of data. An important consideration which is becoming increasingly apparent is that STM research using motor tasks can be more readily controlled experimentally than STM with verbal tasks. Thus, control over rehearsal characterizes motor studies since it is postulated that rehearsal cannot be carried out except by overt means. In verbal studies, however, covert rehearsal can be very difficult to control. Additionally, the past history of the S with respect to the experimental motor task can also be more easily ascertained; this is a virtual impossibility with verbal tasks.

Future research in motor STM can be directed toward finding tasks, or providing training on tasks so that there is no characteristic response set associated with them. This could be accomplished by an empirical selection process, or by providing prior training trials on a particular task so as to eliminate characteristic response set.

While the present paper demonstrated the operation of both proactive and retroactive interference effects in motor-STM, a comparison of the relative strength of these two processes was not possible. In future research, similar designs to the present PI and RI study can be employed with the important exception that the retention intervals between the criterion force and the recall test be held constant for both PI and RI groups. This will enable a more accurate assessment of the relative strength of the two types of interference.

APPENDIX 1

SUBJECT INSTRUCTIONS

Please be seated in the chair. Place both feet flat on the floor and try not to cross your legs during the experiment. Rest your right elbow on this foam pad, and grasp this knob with your right hand in this manner (E demonstrates proper procedure to S). Notice that as I push down on the knob, the line on this screen moves downward from the zero point on the center. The harder I push, the farther down the line moves. Also, when I pull up on the knob, the line moves upward. Upon release on the knob, the line returns to zero. You try it. Grip the knob as I have shown you and pull up and push down several times (Allow S to push and pull a few times without positioning on a number).

Now observe this display here. The numbers 1 through 5 will appear either in this window on the left, indicating a pull, or in this window on the right, indicating a push. For example, if a 2 appears in the left window, you would respond by pulling on the knob until the line rests at 2. If a 2 appears on the right, you would push on the knob until the line rested at 2.

A number will be presented in one of these windows and remain on for six seconds. During that time your task will be to position the line appropriately, and hold it there as accurately as possible until the number goes off; then release the knob, allowing the line to return to zero, and wait for the next number. Following a variable interval of time, the same number will be presented again. However, this time the line will be removed from the screen. You are then to reproduce the first response by using your memory for the "feel" of the force. Thus in your initial response, try to develop an image for the "feeling" of the force required to move the line to the appropriate position. This should help you in your subsequent recall without the line. I will be in the next room recording the accuracy with which you produce the required force from memory. To facilitate this recording, hold this button in your left hand like this, and press it once at the precise moment you feel that you are applying the correct force to the knob.

The exact procedure will be this: with the line present, a number will appear on the display. When it occurs, you move the line appropriately and hold it there until the number goes off. Then wait quietly, but do not release your hand from the knob. Sometime later, the number will appear again, but the line will disappear. Now you attempt to reproduce the indicated force from memory. At the moment that you think you have applied the correct force, press and release the button in your left hand. When the number goes off, release your pressure on the knob, and remain quietly seated until the next number is presented. We will have approximately 20 seconds between trials.

We will now try several simulated trials according to these procedures. (Use card with "3 1/2" to let S practice one Push and one Pull, with a 7 second retention interval. Let S attempt to reproduce the force from memory with screen blank). I will go into the next room and talk to you through the intercom. Do you have any questions?

APPENDIX 2

SUBJECT'S INSTRUCTIONS

Please assume a position in this chair that you can maintain for 45 minutes. We are interested in your ability to remember discrete movements, so we don't want you moving around during the experiment.

This control knob moves in a vertical direction only. Note that as I press down on the control, the horizontal line on the oscilloscope moves down as well. The harder I press down, the farther the line goes down. As I pull up on the control, the line moves upward, and again, the harder I pull up on the control, the further the line moves upward. When I release my pressure on the control, but without letting go completely, the line returns to the center. Here, you try it (allows S̲ to position up and down). Try to grip the control in such a way that movements of the line up and down can be made with the same grip. Note that you are to hold on to the control at all times except when I call you over the intercom and announce a rest break. There will be 3 rest breaks during the experiment, and a tone will be sounded to warn you when the break is over.

Note the windows in this display above the oscilloscope. Numbers will be presented (one at a time) which correspond to the numbers on the face of the oscilloscope. For example, a number occurring in the window here on the left corresponds to movements of pulling up. You are to immediately position the line to the appropriate place until the number goes off. Then relax your pressure, letting the line return to the center position, but remember not to let go of the control. Conversely, numbers appearing in the window to the right correspond to movements downward. Remember that the onset of a number is your cue to immediately position the line appropriately, and hold that position as long as the number remains on. When the number goes out, immediately relax your pressure, but not your grip on the control.

In each trial, a number will be presented twice, once with the line showing on the oscilloscope, and the second time without the line. When you position the line initially, try to remember the "feel" of the force with which you held the control. When the number comes on again, you will have to reproduce the same movement without the visual help of the line. Therefore, it is important that you try to remember the "feeling" of the movement. It is your ability to reproduce the force based upon your kinesthetic cues that we are interested in.

In your left hand I want you to hold this signal marker switch. When you feel you have correctly reproduced the force on the test trial, the second number presented, briefly depress the switch. This will help us in scoring the exact point in your response that you want counted as your best estimate of the force reproduction.

In half the trials, we will ask you to count-backwards during the interval between the completion of the first movement and the retention test. I will call out a three-digit number over the intercom, and you will repeat back that number to insure that you heard it correctly, and immediately begin counting-backwards by 3's. Thus if I said 157, you would repeat 157, then 154, 151, 148, 145, etc. You are to continue counting-backwards as accurately as possible until another number appears on the digit display, requiring a movement. A tone will pulse at the rate of once per second to pace your counting-backwards. Remember, we are recording your performance on this counting task as well, so do your best to stay with the tone without errors. When a number does occur, stop counting and position the line accordingly. On the remaining half of the trials, no number will be called, so you will remain seated quietly until the retention test.

Let us try a simulated trial. Have you any questions?

APPENDIX 3

SUBJECT'S INSTRUCTIONS

Please be seated in this chair. Try to assume as comfortable a position as possible, one that you can remain in throughout the experiment. If you wish to cross your legs, do so and keep them crossed. If not, please do not shift around during the experiment.

Grasp the CONTROL in a manner such that you can make both up and down responses, like this: (gives example). The CONTROL moves only on the vertical plane. Note that the harder I push down, the farther down the line on the scope goes; the harder I pull up, the farther up the line goes. Here, you try it. O.K. that's enough practice.

Now, note this display here. I will present numbers in either of these two windows, corresponding to the positions below the zero point and above the zero point of the scope; thus if a number 2 appears here on the left window here, this would be an indication for you to make the line move up to 2 on the scope, like this; conversely, if the 2 appeared in the right window, it would indicate a 2 down as the appropriate response.

Note that the occurrence of the lighted number is your signal to immediately position the line to the required position, and hold that position as long as the number is lighted. When and only when the number goes off do you release your pressure on the CONTROL. Note that you do not release the CONTROL, only during the rest periods which I signal over the speaker. Each number will come on and remain on for approximately 6 seconds. They will be spaced 4 seconds apart. The first number I present will be the one movement you will have to remember. I will then present a second number, and then the original number without the line to help you. Thus I am interested in how well you can remember the initial movement, so it is important that you try to remember the "feel" of that original movement. Try to develop an image of it to aid in your subsequent recall test, O.K.?

Now, in your left hand I want you to hold this switch. I will be in the next room recording the accuracy of all your responses, but to aid me in ascertaining exactly which part of the test response you want counted, I want you to click this switch with your left hand just at the moment that you feel that you have correctly reproduced the required response. Remember, however, that you are to continue holding the CONTROL position until the number goes off. The onset of the number signals you to initiate the movement, the offset signals you to release the pressure (but not release the CONTROL).

Now, on some trials I am going to call over the intercom a 3 digit number, such as 234. This will be done following the initial number for that trial. Instead of a movement for that trial, a zero will be presented, and you will be required to count-backwards from the number that I present to you, until the recall of the initial number (the initial number is presented). Thus as I repeat 234, immediately you are to begin counting-backwards as fast, yet as accurately as possible, saying, 231, 228, 225, 222, 219, etc. As soon as a number comes on, stop counting and make the appropriate response.

Let me summarize:

First a number will be presented. You position the line appropriately, hold it until the number goes off, then relax your pressure. Remember that this first number is the one which you will be asked to recall, so try to remember the "feel" of it. Next, a second number will be lighted. You position it accurately, and hold it till the number goes off, then relax your pressure. Now, the initial number will come back on, only the line will disappear. You are to try to reproduce that number as accurately as possible, and when you feel you have it, press the switch in your left hand briefly, but don't relax your pressure within the CONTROL until the light goes out. Do not release the CONTROL until I indicate a rest period over the speaker.

On some trials, a zero will appear, and you are not to make any positioning responses. On half of these zero trials E will call out a 3-digit number over the speaker. You are to immediately count-backwards as fast and accurately as possible. Remember I am recording the accuracy of your performance on this task as well. As soon as a number appears (it will be the recall of the first number-scope black), stop counting and make the required movement. Any questions?

Let us go through a simulated trial, O.K.?

APPENDIX 4

SUBJECTS' INSTRUCTIONS

Please be seated in this chair. Try to assume a position which you can remain in for the next 35 minutes. Please do not shift around except when I indicate a rest period over the speaker.

Grasp the CONTROL in a manner which will permit you to make both upward and downward movements without changing your grip, like thus (give example). Note that the harder I push on the control in a vertical direction only, the farther down the line goes, conversely, the harder I pull up on the CONTROL, the farther up the line goes.

Note this display above the scope here. I will present numbers in either of these two windows, which correspond to the numbers on the face of the scope. Thus, if a number 2 appears in this window at the left, this will indicate a response of positioning the line to two (2) increments above the zero, or up 2. O.K.? Also, a number occurring in the display is your signal to immediately make the required positioning movement, hold the position until the number goes out, and relax the pressure when and only when the number goes out.

Note that you maintain your grasp on the CONTROL at all times unless I indicate otherwise over the speaker.

Each number will come on for a period of 6 seconds, then a 4-second dark period, then the second number will be repeated.

In all trials you will be required to remember the force associated with the second number presented. Of course you will still have to accurately position the line for the first number, but your retention for this number will not be tested. Only the second number will require your memory, and the occurrence of the third number will be the test for the second number. The only difference is that the line will be removed from the scope, so you will have to try to remember the feeling associated with the second number. Thus it is important that you try to "feel" the movements, as you make them.

Now in your left hand I want you to hold this switch. I will be in the next room recording the accuracy with which you make your responses, but to aid me in ascertaining exactly which part of the recall test you want counted on the presentation of the third number, I want you to depress this switch very briefly at that point when you feel that you have correctly reproduced the required response. Remember that you are to continue to hold down the CONTROL until the number goes off.

On some trials, the initial number will be a zero. Because the line is already positioned at zero, you will make no movement during this time. Merely remain seated until the second number comes on. Some of these zero trials will be accompanied by my calling out a 3 digit number, such as 234, over the speaker. When you hear this number, repeat it back immediately, and commence counting backwards by 3's. Thus 234 would be followed by 231, 228, 225, 222, etc.

As soon as the second number appears, stop counting and make the required movement. The next number to appear will be identical to the second number. In fact it is the test for the second number. The only difference is that the line on the scope will disappear, and you will have to make the required movement based on your feel for it, just as before. Note that you must try to be as accurate as possible, and as fast as possible. I am recording your performance on this task as well.

Let me summarize the procedures:

A trial consists of the presentation of three numbers in the display. The first number will occur, and you position the line on the scope appropriately. The number conveys much information. First, the side of the display upon which the number occurs indicates whether a push or pull response is appropriate; second, the magnitude of the number indicates how far down or up the movement will be. The onset of the number is your cue to immediately position the line to the required position, while the offset of the number indicates to you to relax your pressure on the control.

The first number to appear must be responded to, but you won't have to remember it. The second number will be tested, so try to remember the force required to reproduce the movement. The third number will be the recall test for the second, and the line will not be present. As soon as you feel that you have reproduced the force as accurately as possible you click the signal marker switch in your left hand. When and only when the number goes out, relax your pressure on the Control. Then sit quietly until the next trial 30 seconds later. After a block of eight trials, I will call you over the speaker and tell you to rest. A couple of seconds later a tone will sound, warning you to be ready for the next series of trials. You may release the Control only during this period. Try to assume the same position and posture for all blocks of trials, and use the same grip for all responses.

Any questions?

APPENDIX 5

SUBJECT'S INSTRUCTIONS

We are interested in the ability of a person to reproduce a motor movement after various amounts of previous practice trials with that same movement. In this experiment, the presentation of a lighted number will define your movement task. Please be seated in this chair. Assume a comfortable position which you can remain in for the remainder of the experiment.

Grasp the CONTROL in a manner such that you can make both up and down movements with the same grip, like this: (E gives example). The CONTROL moves only in the vertical plane. Note that the harder I push down, the farther down the beam on the oscilloscope goes, and the harder I pull up, the farther up the beam goes. Here, you try it. O.K., that's enough practice.

Now note the display. I will present numbers in either of these two windows, corresponding to the positions on the scope both above and below the centerline. If a number 2 appears here on the left, this is your cue to make the beam move up these 2 centimeters, like this (give example). Conversely, if the two occurred in the window to the right, it would indicate a 2-down as the appropriate movement response.

The appearance of the lighted number is your signal to immediately position the beam to the appropriate position, and hold that position as long as the number stays lighted. Only release your pressure when the number goes off. Do not release your grip on the control.

Each number will come on, and remain on for approximately 6 seconds. During that time, you are to position to beam accordingly, hold the position until the number goes off. Group A will receive only one opportunity to position the beam prior to the recall test. Thus after the number goes off, these _S_s will remain quietly seated during the 20 second retention interval. Then the number will come on again, only this time the beam will disappear from the scope, and the force movement will have to be accomplished by the "feel" of the pressure in positioning the beam. As before the light will control the onset and offset of the recall response too. In your left hand is a spring-loaded switch which you are to press once very briefly only during the recall test. This will aide us in scoring your response later. Group B: You will have 3 practice trials on positioning the beam before the recall test. Thus a number will come on as before for 6 seconds, go off for 4 seconds, come back on for 6 seconds, etc. The onset and offset of the number defines your movements. Your recall test will be identical to the above. Group C: You will have 7 practice trials at positioning the beam prior to the recall test, identical to the instructions for one practice trial, except the successive numbers will be presented with 4 seconds separating them.

The retention intervals will be the same 20 seconds as for all other groups.

APPENDIX 6

SUBJECT'S INSTRUCTIONS

We are interested in a person's ability to reproduce a motor task after various practice trials. In the present experiment, we will present a lighted digit here on this display. The location and magnitude of the digit will define your response. Thus if the number 2 appears here on the left this will be your cue to respond with moving the beam on the scope to position 2-up, conversely, if the number 2 occurs on the right, you would position the beam to 2-down (gives example).

Grasp the control in a manner such that you can make both up and down movements with the same grip. The control moves only in a vertical plane, note that the harder one pushes, the further down the beam moves, and the harder one pulls, the further up the beam moves. Here, you try it. O.K., that's enough practice.

The occurrence of a digit is your signal to immediately position the beam, hold that position as long as the number is lighted, and release your pressure when the number goes out. Do not release the control, only your pressure on it.

Each number will come on, remain on for approximately 6 seconds, then go out. A dark interval of 4 seconds will occur during the successive practice trials. You will receive 7 such numbers, and will be required to position the beam appropriately each time the number goes on, and release your pressure each time the number goes out. Try to get the feel of the pressure required to make the appropriate response, as on the recall test, the beam will disappear, and you will need to use your memory for the feeling of the force.

Immediately after the final practice number (half the trials will have 7 and half one practice movement) during the 20 second retention interval, you will have to count-backwards by three's. I will call out a three digit number over the intercom, and you must immediately repeat it back and commence counting in pace with an auditory signal which will help you to keep time. Continue counting until the number comes on signifying recall of the digit. The switch in your left hand must be activated just as you feel that you have successfully repeated the test force. This is hooked up to the recording apparatus and will enable us to score your responses more accurately.

You will have only six trials, so the experiment will be very brief. Do your best. Any questions?

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