

Behavioral and Methodological Issues in Motor Short-Term Memory and its Basic Experimental Paradigm

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Abstract

We examined in this study the basic behavioral correlates of motor short-term memory and several methodological issues with respect to the investigative paradigm. We first reviewed pioneering studies on motor short-term memory and then addressed methodological issues including dependent measures, directional biasing effects, and separation of movement cues. Finally, we examined the methodological aspects of the typical investigative paradigm used in motor short-term memory research.

Introduction

The behavioral aspects of short-term memory have been intensively investigated by psychologists since the 1950s, with the main issue in the 1950-1960s being the mechanisms of forgetting in verbal short-term memory (e.g., Brown, 1958; Peterson & Peterson, 1959; Keppel & Underwood, 1962). Following the early psychological studies of forgetting in verbal short-term memory, a number of investigators first became interested in the short-term retention of motor information and also in the similarities and differences between verbal and motor short-term memory in the mid-1960s (e.g., Adams & Dijkstra, 1966; Boswell & Bilodeau, 1964; Posner, 1967). These pioneering studies regarding motor short-term memory provided a basic framework for extensive experimental investigations of motor short-term memory. In this article, we first review these early pioneering studies of motor short-term memory, and we then address several methodological issues, such as dependent measures, directional biasing effects typically observed in short-term retention of motor information, and separation of movement cues. Finally, we examine the basic investigative paradigm used in motor short-term memory research, referring to the starting position manipulation, the presentation of criterion movements, and the methods of the return to the

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starting position between the criterion and reproduction movements.

Pioneering Studies

Adams and Dijkstra (1966) conducted studies of forgetting and reinforcement in the short-term retention of simple motor responses, using a linear positioning apparatus first developed by Boswell and Bilodeau (1964). Subjects were asked to move a handle to a stop and to then reproduce the movement following retention intervals ranging from 5 to 120 sec. Three different levels of reinforcement were used, with the subjects being asked to repeat the correct movement 1, 6 or 15 times prior to each retention interval. The reproduction accuracy decreased as the duration of the retention interval increased, and increased with the number of repetitions. Thus, the findings were parallel to those of corresponding studies of retention and reinforcement in verbal short-term memory conducted by Peterson and Peterson (1959). Adams and Dijkstra's findings regarding the forgetting of kinesthetic information were confirmed by Posner and Konick (1966). However, Posner and Konick also observed a fundamental difference from the findings for verbal short-term memory, specifically, that the forgetting of kinesthetic information was apparently not a function of interpolated task difficulty. Posner (1967) further investigated differences between the retention characteristics of visual and of kinesthetic information by comparing the reproduction accuracy in blind positioning movements with that in visually guided movements. The reproduction of the blind movements showed rapid forgetting when the retention interval (20 sec) was unfilled, but was not affected by an interpolated attention-demanding task (a digit classification task). In contrast, the visually guided movements showed no forgetting with an unfilled interval, but considerable forgetting with the addition of an interpolated task. Based on the finding that visual and kinesthetic information were affected differently by the interpolated task, Posner suggested that the retention of kinesthetic information is much less affected by the availability of central processing capacity than is the retention of visual information.

The absence of any interference due to the addition of an interpolated task in Posner's (1967) study may have been simply a consequence of dissimilarity between the digit classification task, used as the interpolated task, and the motor response required in the criterion and reproduction movements. This seems quite probable, given that interpolated motor tasks have been found, in a number of subsequent studies, to influence the reproduction of motor responses (Laabs, 1974; Pepper & Herman, 1970; Stelmach & Kelso, 1975; Stelmach, Kelso, & McCullagh, 1976; Stelmach & Walsh, 1972, 1973). The measures of recall performance used in these later studies were also different from the measure originally used by Posner (1967). Posner used absolute errors (AE) as forgetting scores, whereas more recently researchers (e.g., Stelmach & Kelso, 1975; Stelmach & Walsh, 1972, 1973) have used not only AE but also constant errors (CE) and variable errors (VE). It is

noteworthy that Adams and Dijkstra (1966) also employed AE as their measure of forgetting but also briefly reported CE scores, although without explanation. Since there has been considerable controversy regarding the usage of these error measures, we refer in the following section to some methodological issues with respect to the three error measures.

Pepper and Herman (1970) conducted a series of experiments on motor short-term memory using a force response. They believed that the use of the force response as a basic motor function would permit an analysis of the general findings obtained in prior studies of motor short-term memory using movement extent. Retention of the original force response was measured by both AE and CE (algebraic error). Their results revealed an overshooting response set, quite in contrast to the earlier studies concerning the retention of movement extent (e.g., Adams & Dijkstra, 1966), in which the subjects were primarily found to use undershooting response sets. However, Pepper and Herman's scrutiny of algebraic errors (i.e., CE) of both the earlier and their own studies revealed some consistencies irrespective of the different response set. They noted that CE moved in the negative direction over time for unfilled retention intervals while it moved in the positive direction when the intervals were filled with non-motor activities (such as counting backward or classifying digits) or when the criterion motor act involved substantial repetitions. Pepper and Herman also found, in their own studies, that CE shifted in the direction of the mean magnitude of the interpolated and criterion forces.

Based on these findings, Pepper and Herman proposed a model incorporating two concepts regarding the memory processes and decay and interference as causes of forgetting. The decay of a memory trace in the memory processes over an unfilled retention interval was considered to involve a diminution in the representation of the intensity or the extent of the criterion motor activity. The change in the intensity or extent of the criterion motor activity was considered to represent the mean effect of the proprioceptive stimulation arising from the criterion motor task, the interpolated task, and the level of prevailing muscle tension. Such mean intensity represented in memory would increase if the interpolated motor task were of greater magnitude than the criterion task, but would decrease if the interpolated task were of lesser magnitude. Thus, Pepper and Herman's model hypothesized that the directional error (i.e., CE) in the motor response is caused by an assimilation effect, predicting that the error always shifts in the direction of the postulated mean intensity. Clearly, this model emphasizes the change in response bias, and has a reliance on CE as the primary indicator of the effects of decay and interference on motor short-term memory.

The pioneering studies of Pepper and Herman (1970) provided a framework for extensive experimental investigations of motor short-term memory. In subsequent studies of motor short-term memory, the emphasis shifted away from explaining the nature of forgetting of motor information toward examining the specific aspects of encoding and retention of movement information. The investigation of the respective encoding and retention of

location and distance cues, as the primary sources of movement information, has dominated motor short-term memory research and models since the early 1970s (Jones, 1974; Kelso, 1977b; Laabs, 1973; Roy, 1978; Stelmach, Kelso, & Wallace, 1975), and the basic investigative paradigm is established. Before reviewing this paradigm in motor short-term memory research, we examine some widely accepted explanations for forgetting of motor information as well as several methodological issues, such as dependent measures, response biasing effects and separation of movement cues, in the study of motor short-term memory.

Mechanisms of Forgetting of Motor Information

Decay

The two widely accepted explanations for forgetting of verbal information, decay and interference, have also been advanced to explain the loss of motor information over time. Early studies of motor short-term memory demonstrated rapid forgetting of kinesthetic information as a negative shift in directional recall error during an unfilled retention interval (Adams & Dijkstra, 1966; Marshall, 1972), but failed to show any additional decrements in performance due to information-processing activity during the retention interval (Posner & Konick, 1966; Posner, 1967). These initial findings suggested that forgetting of movement information arising as time-order error is caused by the decay of the memory trace over time. Such negative time-order error has also frequently been reported in perceptual judgment studies (see Laabs & Simmons, 1981). These studies of motor short-term memory used primarily AE and/or CE scores, although a number of studies have also shown that forgetting also results in reliable increases in VE (Keele & Eills, 1972; Laabs, 1973, 1974; Marteniuk, 1977; Shea, 1977; Stelmach et al., 1975, 1976).

Interference or Assimilation

In interference theory, forgetting is assumed to be the result of competing responses learned either before (proactively) or after (retroactively) a criterion movement (Stelmach, 1982). It has been shown that retroactive inhibition is more potent than proactive inhibition in interfering with the retention of information in motor short-term memory (Craft, 1973; Herman & Bailey, 1970). Many studies have used the paradigm of retroactive inhibition with some interpolated movements presented during the retention interval (Dickinson, 1977; Hagman, 1978; Hagman & Williams, 1977; Stelmach, 1970; Stelmach & Wilson, 1970). Although the findings of the studies employing task-related interpolated movements (i.e., movements that are quite similar to the criterion movement) have been quite variable, the amount of interpolated activity appears to be directly related to increased forgetting (Stelmach, 1982). As a model of forgetting, Pepper and Herman (1970) postulated, as mentioned in the preceding section, that the effect of forgetting on CE depends on the intensity of the memory trace, that is, interpolated activity increases the intensity of the memory trace, and that the intensity decreases during an unfilled retention in-

interval. When the retention interval is filled with a task-related motor activity, response performance is shifted in the direction of the relative intensity of the interpolated task, and this directional shift of the response is seen in an assimilation effect. The concept of an assimilation effect was also used in interpreting the central tendency effect (see the biasing effects section in this article) by Laabs (1973), who suggested that interpolated movements affect and change the "average" movement trace that is developed by similar criterion and reproduction movements, and that changes in this referent movement trace seem to be responsible for shifts in response bias.

Dependent Measures of Recall Performance

In studying the retention of movement information over time, it is essential to have a measure (or measures) of recall performance which accurately reflects the characteristics of motor short-term memory storage. Stelmach (1969) noted that a major difficulty in making a comparison between the recall of verbal information and that of motor information was that the recall response for verbal items was usually evaluated as simply either right or wrong, whereas the recall of motor information may be sensitively measured in degrees of accuracy with respect to the target response. Although the earlier studies used either AE alone (Posner, 1967) or AE in combination with CE (Adams & Dijkstra, 1966; Pepper & Herman, 1970), in more recent studies three error scores are usually reported in an attempt to more fully evaluate different aspects of the retention of movement information.

CE, constant error, is the algebraic error between the recall response and the correct response, and provides an indication of the response bias (i.e., undershooting or overshooting) of the subjects. AE, absolute error, is the absolute value obtained by ignoring the sign of the CE, and is used as a measure of overall accuracy. VE, variable error, is the standard deviation of a subject's responses about his/her own mean CE, and is used as an index of the individual subject's response consistency, or variability.

There has been considerable disagreement about which of these measures provides the best indicator of movement recall performance. Schutz and Roy (1973) presented a statistical treatment of the relationships among the three measures of CE, VE and AE. Under the assumption of a normal distribution, AE is completely dependent on both CE and VE, which, in turn, are statistically independent. Thus, AE can be predicted from CE and VE. AE is strongly influenced by CE when the latter deviates markedly from zero, is determined by VE when CE is equal to zero and reflects some unknown combination of CE and VE when the deviation of CE from zero is less than approximately two standard deviations. Schutz and Roy suggested that AE is the variable which must be eliminated from reports on recall performance and argue that the joint use of the other two statistics, CE and VE, is the most appropriate means of describing performance. It should be noted that Safrit, Spray, and Diewert (1980) have reported that the reported distributions of AE and VE scores are

not always normal, while that of CE scores may be normal, suggesting that the analyses of these three error scores may require different statistical procedures. However, Safrit et al. argue that the statistical characteristics of non-normal AE distributions alone should not prevent investigators from examining recall performances in terms of AE scores, because the selection of error measures should be based not only on purely statistical considerations but also on the behavioral dimensions which these measures reflect. Accordingly, Safrit et al. suggest that Schutz and Roy's reservations regarding the use of AE scores are applicable only if the most meaningful behavioral constructs are reflected in CE and VE scores.

In contrast to Schutz and Roy (1973), Henry (1974, 1975) has suggested that a single error score is more meaningful than joint scores in describing the degree of approximation to the target of response by the subject, and has recommended the use of a composite error score, $E [(CE^2 + VE^2)^{1/2}]$, as the best measure of individual errors about the target. Henry argues for the use of E rather than AE, because the latter fails to accurately reflect the contributions of CE and VE scores. However, few studies have employed the composite error score E in motor short-term memory research. Schutz (1974) maintained that composite error scores (either E or AE) are not interpretable indicators of motor performance. This position, advocating the use of both CE and VE instead of either AE or E alone, has been supported by Poulton (1981), who argued on the grounds of the statistical independence of CE and VE scores. However, Newell (1976) suggested that, if the researcher asks the subjects to respond as accurately as possible (i.e., to reduce AE scores) and measures motor performance in terms of error scores, the judicious use of AE is appropriate and that the combined use of both CE and VE scores may be useful in the analysis of the strategies used by the subjects in their attempts to reduce AE scores. Roy (1976) also suggested that all three measures, CE, VE, and AE (or E), should be considered in the analysis of motor performance, proposing the routine use of multivariate analysis (MANOVA) with the three dependent measures in all studies of motor short-term memory. Regarding the use of a MANOVA, Thomas (1977) has argued that such an analysis procedure would be inappropriate when AE is highly correlated with CE and/or VE (see also Thomas & Nelson, 1990, p.159). Based on theoretical considerations, Spray (1986) has suggested that, although both composite error measures (E and AE) are fairly strong indicators of target accuracy, AE may be an even stronger accuracy indicator than E for most reasonable accuracy requirements, and that CE and VE are required to define the performance characteristics (i.e., response bias and variability) of the accuracy in relation to the target. Thus, Spray argues that AE may frequently be the best and most appropriate single indicator of overall accuracy. In some cases, however, the analysis of AE may be unnecessary if the primary interest is in response bias and variability—characteristics which are best measured with CE and VE (Spray, 1986).

Biasing Effects on Recall Performance

The Range or Central Tendency Effect

The range or central tendency effect also presents problems for the researcher interested in measuring motor short-term memory. Searle and Taylor (1948) were probably the first to report the tendency for subjects to undershoot the target in tasks in which the extent of required movement was relatively long and to overshoot the target when it was relatively short, terming this tendency the "range effect". Such an effect was also evident in Slack's (1953b) experiment in which the subjects tracked steps of ten different sizes. The subjects tended to overshoot the small steps, of 0.25 in., and to undershoot at the larger steps, of 2.5 in. This range effect has occasionally been referred to as the central tendency effect (Laabs, 1973), a term which can be traced back to Hollingworth (1910). The range or central tendency effect has been observed not only in tracking tasks (Searle & Taylor, 1948; Slack, 1953a, 1953b) but also in tasks requiring a positioning response (Brown, Knauff, & Rosenbaum, 1948), and has been demonstrated in many experiments in which a range of movements of different sizes is used (Colley & Colley, 1981; Duffy, Montague, Laabs, & Hillix, 1975; Johnson & Simmons, 1980; Keele & Ells, 1972; Marteniuk, 1973, 1977; Marteniuk, Shields, & Campbell, 1972; Stelmach, 1970; Yasuyoshi & Naruse, 1978).

While the cause of this phenomenon is open to question (Stamm & Kelso, 1978), it seems reasonable to suggest that the central tendency effect will occur within the range of movements used in any experiment in which each subject receives a number of different sizes of movements (Marshall, Anderson, & Kozar, 1992). The subject learns the middle of the range of sizes as the experiment proceeds, and this information regarding the middle of the range comes to affect the responses made to all movement sizes (Poulton, 1973, 1975, 1981). Laabs (1973) has also noted that movement reproduction is made in reference to an "average" or "central" movement trace in addition to the memory trace of the actual movement. This referent movement trace is constituted of the combination of movements to be reproduced, and is similar in concept to a movement representing the current adaptation level (Helson, 1964). Response bias occurs in the direction of this referent movement trace. If this is indeed the case, the central tendency effect should become more pronounced and more specific to the range of sizes used in an experiment as the experiment proceeds (Poulton, 1981). Colley and Kitchen (1983) have presented evidence consistent with this deduction; criterion movements were found to be affected by preceding movements, and the central tendency effect increased as the experiment proceeded. When an experiment is carried out under several conditions, the serial position of the conditions is usually balanced over a group of subjects so that any gradual deterioration in performance due to fatigue or boredom can be excluded from comparisons between conditions. Poulton (1973, 1975, 1981) has pointed out that, although the effects of fatigue and boredom may be eliminated by the balanced design for the serial position of the conditions, the performance under each condi-

tion remains biased by the central tendency of the preceding set(s) of conditions. The only means of avoiding the central tendency effect is to use only the results obtained under the condition presented first or to use a between-subject design (Poulton, 1981).

The Effect of Interpolated Movements

The introduction of interpolated movements, deviating markedly in extent from the to-be-recalled criterion movements, has been shown to produce considerable directional shifts in the CE associated with reproduction movements (Stelmach, 1974). Craft and Hinrichs (1971) observed that directional shifts in CE were inversely related to the similarity between the criterion and the interpolated movement. This was differentially set for specific attributes of movements. Laabs (1974) showed that the end-location of the interpolated movement caused directional biasing in CE for the reproduction of criterion movement location, while the distance of the interpolated movement caused directional biasing for the reproduction of criterion movement distance. Thus, the magnitude of response biasing caused by interpolated movements may be dependent on the relative amplitude of the interpolated and criterion movements (Craft & Hinrichs, 1971).

Stelmach and Walsh (1972, 1973) found that response biasing can also be influenced by the duration of time spent at an interpolated location and by the recency of the interpolated activity. Recency is defined as the time delay between the presentation of an interpolated activity and the reproduction of the criterion movement. They concluded that the increased response biasing which occurs over time is due to the decay of the memory trace of the criterion movement, whereas any decreased biasing may be due to decay of the trace of the interpolated movement. In addition, the response biasing can be reduced when the criterion movement trace is reinforced by repeating the criterion movement a number of times or by providing augmented feedback (Stelmach & Kelso, 1975). Thus, the strength of the memory trace is apparently a potent variable influencing the assimilation effect in motor short-term memory. Response biasing has also been suggested by Stelmach et al. (1976) to appear to the same extent for both preselected (subject-defined) movements and constrained (experimenter-defined) movements, and for both pre-cuing and post-cuing instructions with respect to the to-be-reproduced movements (Craft, 1973). These findings suggest that the assimilation effect and response biasing may be the result of peripheral influences, such as those arising from movement itself, rather than of any central factors (Stelmach et al., 1976; Stelmach & Kelso, 1975). This point of origin has been emphasized by Carlton and Carlton (1984), who suggested that the biasing effect may occur at relatively low levels of the control system, such as at the level of spinal motor neurons.

Spatial Reference Points

Poulton (1979, 1981) proposed an alternative explanation for forgetting and response biasing. Response biasing, which is operationally defined as the effect of forgetting on CE, is postulated by Poulton to be a function of the spatial reference points that the experimental

equipment and procedure provide for the subject. When forgetting is complete, the average CE is believed to be determined entirely by the spatial reference points. Poulton attempted to explain the results of several earlier studies using spatial reference points as a starting assumption. According to Poulton, when the subject has no reference points during movement tasks (as in the case of the experiment conducted by Keele & Ells, 1972), forgetting simply increases the central tendency effect. When the subject is asked to perform angular arm movements in a symmetrical area (Laabs, 1973), the spatial reference points are symmetrical, and hence, forgetting increases the central tendency effect. When the reference point is beyond the end of the range of the movements (Ho & Shea, 1978; Stelmach et al., 1976), all the responses are affected by this reference point, resulting in overshooting. Poulton's model is therefore based on the concept of an assimilation effect balancing actual responses and the spatial reference points defined by the experimental equipment and procedure.

Separation of Movement Cues

Although a number of earlier studies of motor short-term memory focused on the nature of forgetting of overall movement information, Posner (1967) was probably the first to investigate the forgetting of separate components of a movement (i.e., distance and location). In his experiment, the subjects were asked to make an original movement and remember its distance, and then, after a retention interval, to reproduce this original movement distance. Subjects in one group made reproduction movements from a starting position different from that of the original movements, while subjects in another group attempted to reproduce their original movements from a starting position identical to that used in the original movement. Since the latter group of subjects made their reproduction movements from an identical starting position, it cannot be determined which cues (location or distance) they actually used to achieve the goal of reproducing distance. The design of this initial study precluded the reliable differentiation of the role of distance and location cues in movement reproduction. In Stelmach's (1970) experiments, subjects were asked to reproduce the target location of the criterion movements from one of two starting positions, each differing from the starting position of the original criterion movement. This manipulation of the starting position therefore rendered the distance moved as an unreliable cue for the recall of location. Stelmach, however, based on this experiment, discussed the nature of forgetting of kinesthetic information without referring to the location component of movement. He (spuriously) compared his data with those of Adams and Dijkstra (1966), who used an identical starting position for both criterion and reproduction movements, even though it was apparent that the subjects in the earlier study could use distance as well as location cues for movement reproduction.

To investigate the response sensitivity of location and distance cues in the reproduction

of a horizontal angular arm movement, Marteniuk et al. (1972, Experiment 2) employed an experimental procedure with variable starting positions. For the reproduction movements, three different starting positions, which were shifted from the original criterion starting position towards the criterion end point, were used to separate location and distance cues. The accuracy of reproduction of the end-location of the criterion movements by the subjects in the location group was not different from that by a group performing with both cues available (i.e., a group reproducing movements from an identical position for both criterion and reproduction movements), whereas the subjects in the distance group reproduced movement with greater error than the subjects in the other two groups. This finding indicated that distance information was not as codable or reliable as location information. Marteniuk and Roy (1972) replicated these findings by conducting similar experiments using a procedure in which starting positions were varied. They also found that subjects consistently undershot the required distance when only distance cues were available, whereas subjects who were asked to reproduce the end-location of the criterion movement consistently overshot the target. Keele and Ells (1972) also reported response bias results similar to those reported by Marteniuk et al. (1972). Furthermore, they found that forgetting in the location cue group occurred primarily when a digit-classification task filled the retention interval. They suggested that different movement cues have different retention characteristics, and that location cues may be rehearsable while other cues (such as distance) are not.

It is now apparent that in these early studies location and distance cues were not completely separated. To independently investigate the retention characteristics of these two cues, Laabs (1973) introduced a procedure in which the starting positions of all reproduction movements differed from those of the preceding criterion movements, and a large number of different starting positions were used instead of two or three fixed positions, as used by Keele and Ells (1972) and Marteniuk et al. (1972). In his experiments, Laabs used six movement distances and 12 final locations to make distance unreliable when the subjects reproduced the end-location of the criterion movements, and to make location unreliable when they reproduced the distance moved. VE was used as the index of decay and interference. The results revealed that distance information decayed over an empty retention interval while location information changed very little. In addition, location information was subject to interference from mental activity during the retention interval, while distance information was affected no more than it was during the unfilled interval. These findings were generally in agreement with those of both Keele and Ells (1972) and Marteniuk and Roy (1972) in suggesting that location information may be centrally coded and is more reliable in reproducing movements than is distance information.

The Basic Investigative Paradigm: Methodological Issues

The basic paradigm used for investigating the behavioral aspects of short-term memory of limb movements consists of having a blindfolded subject perform a criterion movement on either a linear or angular positioning apparatus and then reproduce this movement either immediately or after a delay predetermined by the experimenter. In these concluding sections, we examine three crucial factors involved in the basic experimental paradigm used in motor short-term memory research. They are: the manipulation of the starting positions for separating location and distance cues; the two different types (preselected and constrained) of presenting criterion movements; and the three different methods of returning the subject's hand to the starting position for the next reproduction movement after the completion of the criterion movement.

Starting Position Manipulation

Following Laabs' (1973) studies, most subsequent studies have employed a similar procedure for manipulating the starting positions to separate location and distance cues. The basic paradigm involves a criterion movement and the reproduction of this criterion movement with or without a delay (retention) interval. When a reproduction movement begins at the same starting position as that of the preceding criterion movement, the subject can rely on information regarding both the end-location and the distance of the criterion movement for recall. In the separate examination of the retention characteristics of each cue, the starting position for the reproduction movement is altered in order to make the information from the other cue unreliable. For example, when subjects are required to reproduce a given movement distance from an altered starting position, the end-location of the criterion movement is no longer a reliable cue for movement reproduction. Likewise, the distance moved on the criterion movement becomes unreliable in reproducing the end-location of the criterion movement when the reproduction movement commences at a starting position different from that of the preceding criterion movement. Such experimental manipulation of starting positions has therefore been used in an attempt to separately investigate the retention characteristics of location and distance cues in motor short-term memory. However, location and distance cues have more recently suggested to be inseparably coded in memory (Walsh, Russell, & Imanaka, 1980; Walsh, Russell, Imanaka, & James, 1979). This would indicate that the starting position manipulation used in motor short-term memory experiments should be regarded as one designed to direct the subject's attention towards specific movement cues rather than as an effective method of separating different types of movement information to be stored in memory (see Imanaka & Abernethy, 1992).

Constrained and Preselected Movements

Throughout the history of motor short-term memory research, two different methods have been used to present criterion movements: constrained movements (as termed by Jones, 1974) and preselected movements (as termed by Stelmach et al., 1975). In early

studies, the criterion movements were determined by the experimenter—the subject performed a criterion movement until contact with a mechanical stop preset by the experimenter (e.g., Keele & Ells, 1972; Laabs, 1973; Marteniuk & Roy, 1972). This type of movement presentation is now termed constrained. In preselected movements, the subject is allowed to terminate the criterion movement at his/her own preselected position, without the constraint of the movement by a mechanical stop used in constrained movements (Jones, 1972, 1974; Marteniuk, 1973; Stelmach et al., 1975). Both constrained and preselected movements as described herein are made actively by the subject. In an attempt to alter the efferent information available for movement control, Kelso (1977b) introduced passive preselected movements, in which the subject's arm is moved by the experimenter until the subject verbally indicates the end of the movement. It has been consistently found that active preselected movements are reproduced more accurately than are active constrained movements (Kelso, 1977b; Kelso & Frekany, 1978; Stelmach et al., 1975, 1976), passive preselected movements (Kelso, 1977b), or passive constrained movements (Kelso, 1977b; Stelmach et al., 1975). In general, active movements are reproduced more accurately than passive movements and preselected movements are reproduced more accurately than constrained movements.

Return to Starting Position

On completion of the criterion movement, the subject's hand must be replaced from the end position of the criterion movement to the starting position for the next reproduction movement. The movement in replacing the hand is thought of as an interpolated motor activity, and the nature of this replacement movement can considerably affect the response accuracy and bias in the reproduction movement. Three quite different methods have been used to return the subject's hand to the desired starting position for the reproduction movement. After completing the criterion movement, the subject maintains his/her grip on the handle of the apparatus and the handle is moved back to the starting position either by the subject (e.g., Adams & Dijkstra, 1966; Boswell & Bilodeau, 1964; Roy & Diewert, 1975) or by the experimenter (e.g., Kelso, 1977a, 1977b). Alternatively, the subject may release the handle after the criterion movement and place his/her hand someplace such as the lap, while the handle of the positioning apparatus is moved back to the required starting position by the experimenter (e.g., Keele & Ells, 1972; Kelso & Frekany, 1978; Laabs, 1973; Marteniuk, 1973; Marteniuk & Roy, 1972; Posner, 1967; Stelmach et al., 1975).

Marteniuk (1977) compared these three methods and found that the disengaged method produced the least forgetting of movement information during a 20-sec retention interval. For movements with relatively long distance, in particular, the variability of the reproduction movement with the engaged methods was greater than that with the disengaged method. Because of the different influences on recall performance resulting from these three methods, Poulton (1981) pointed out that the returning method used in an

experiment should not be altered under any of the conditions employed in the experiment. Nevertheless, in a few studies, different returning methods have been used under different experimental conditions within the same experiment. For example, in some studies subjects in the active movement condition moved their hand to the new starting position by themselves, whereas in the passive movement condition the experimenter moved the subject's hand to the new starting position for them (Jones, 1972, 1974; Jones & Hulme, 1976). In such cases, differences between active and passive conditions may be confounded by the effects of differences in the kind of interpolated motor activity presented under the two conditions.

Conclusions

The three aspects, discussed in the previous sections, which are involved in the basic paradigm used in motor short-term memory experiments may well affect the retention characteristics of movement information stored in short-term memory, thereby influencing reproduction performance. The basic experimental paradigm should therefore be used carefully in investigations of aspects of motor short-term memory, with careful consideration of several crucial experimental conditions which are involved in the basic paradigm. In addition, reproduction performance is necessarily mediated by both peripheral kinesthetic information and motor commands provided through relevant sensorimotor functions in the central nervous system (see Imanaka & Funase, 1992) as well as by movement information stored in memory, as discussed in this review article. Combined consideration of the neurophysiological aspects of perceptual and motor functions in the brain as well as the behavioral and psychological aspects of memory processes in research on motor short-term memory will probably provide much informative knowledge for further understanding of the processes and characteristics of motor short-term memory.

References

- Adams, J.A., & Dijkstra, S. (1966). Short-term memory for motor responses. *Journal of Experimental Psychology*, *71*, 314-318.
- Boswell, J.J., & Bilodeau, E.A. (1964). Short-term retention of a simple motor task as a function of interpolated activity. *Perceptual and Motor Skills*, *18*, 227-230.
- Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, *10*, 12-21.
- Brown, J.S., Knauft, E.B., & Rosenbaum, G. (1948). The accuracy of positioning reactions as a function of their direction and extent. *American Journal of Psychology*, *61*, 167-182.
- Carlton, L.G., & Carlton, M.J. (1984). A note on constant error shifts in post-perturbation responses. *Journal of Motor Behavior*, *16*, 84-96.
- Colley, A., & Colley, M. (1981). Reproduction of end-location and distance of movement in early and later blinded subjects. *Journal of Motor Behavior*, *13*, 102-109.

- Colley, A., & Kitchen, S. (1983). Criterion movements in motor short-term memory experiments. *Acta Psychologica*, *53*, 119–128.
- Craft, J.L. (1973). A two-process theory for the short-term retention of motor responses. *Journal of Experimental Psychology*, *98*, 196–202.
- Craft, J.L., & Hinrichs, J.V. (1971). Short-term retention of simple motor responses: Similarity of prior and succeeding responses. *Journal of Experimental Psychology*, *87*, 297–302.
- Dickinson, J. (1977). Adaptation level and retroactive interference in motor short-term memory. *Perceptual and Motor Skills*, *44*, 691–694.
- Duffy, T.M., Montague, W.E., Laabs, G.J., & Hillix, W.A. (1975). The effect of overt rehearsal on motor short-term memory. *Journal of Motor Behavior*, *7*, 59–63.
- Hagman, J.D. (1978). Specific-cue effects of interpolated movements on distance and location retention in short-term motor memory. *Memory and Cognition*, *6*, 432–437.
- Hagman, J.D., & Williams, E. (1977). Use of distance and location in short-term memory. *Perceptual and Motor Skills*, *44*, 867–873.
- Helson, H. (1964). *Adaptation-level theory*. New York: Harper & Row.
- Henry, F.M. (1974). Variable and constant performance errors within a group of individuals. *Journal of Motor Behavior*, *6*, 149–154.
- Henry, F.M. (1975). Absolute error vs “E” in target accuracy. *Journal of Motor Behavior*, *7*, 227–228.
- Herman, L.M., & Bailey, D.R. (1970). Comparative effects of retroactive and proactive interference in motor short-term memory. *Journal of Experimental Psychology*, *86*, 407–415.
- Ho, L., & Shea, J.B. (1978). Levels of processing and coding of position cues in motor short-term memory. *Journal of Motor Behavior*, *10*, 113–121.
- Hollingworth, H.L. (1910). The central tendency of judgment. *Journal of Philosophy, Psychology and Scientific Methods*, *7*, 461–469.
- Imanaka, K., & Abernethy, B. (1992). Cognitive strategies and short-term memory for movement distance and location. *Quarterly Journal of Experimental Psychology*, *45A*, 669–700.
- Imanaka, K., & Funase, K. (1992). Kinesthetic information and sensorimotor functions for the control of limb movement. *Bulletin of the Faculty of Liberal Arts, Nagasaki University, Natural Science*, *32*, 235–262.
- Johnson, R.W., & Simmons, R.W. (1980). Extent of movement, terminal position, and practice as determinants of the range effect. *Perceptual and Motor Skills*, *50*, 1019–1022.
- Jones, B. (1972). Outflow and inflow in movement duplication. *Perception & Psychophysics*, *12*, 95–96.
- Jones, B. (1974). Role of central monitoring of efference in short-term memory for movements. *Journal of Experimental Psychology*, *102*, 37–43.
- Jones, B., & Hulme, M.R. (1976). Evidence for an outflow theory of skill. *Acta Psychologica*, *40*, 49–56.
- Keele, S.W., & Ells, J.G. (1972). Memory characteristics of kinesthetic information. *Journal of Motor Behavior*, *4*, 127–134.
- Kelso, J.A.S. (1977a). Motor control mechanisms underlying human movement reproduction. *Journal of Experimental Psychology: Human Perception and Performance*, *3*, 529–543.
- Kelso, J.A.S. (1977b). Planning and efferent components in the coding of movement. *Journal of Motor Behavior*, *9*, 33–47.

- Kelso, J.A.S., & Frekany, G.A. (1978). Coding processes in preselected and constrained movements: Effect of vision. *Acta Psychologica*, 42, 145-161.
- Keppel, G., & Underwood, B.J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Verbal Learning and Verbal Behavior*, 1, 153-161.
- Laabs, G.J. (1973). Retention characteristics of different reproduction cues in motor short-term memory. *Journal of Experimental Psychology*, 100, 168-177.
- Laabs, G.J. (1974). The effect of interpolated motor activity on the short-term retention of movement distance and end-location. *Journal of Motor Behavior*, 6, 279-288.
- Laabs, G.J., & Simmons, R.W. (1981). Motor memory. In D.H. Holding (Ed.), *Human skills* (Chapter 6, pp. 119-151). New York: John Wiley & Sons.
- Marshall, P.H. (1972). Recognition and recall in short-term motor memory. *Journal of Experimental Psychology*, 95, 147-153.
- Marshall, P.H., Anderson, T., & Kozar, B. (1992). Systematic bias in successive movement repetitions. *Journal of Motor Behavior*, 24, 355-358.
- Marteniuk, R.G. (1973). Retention characteristics of motor short-term memory cues. *Journal of Motor Behavior*, 5, 249-259.
- Marteniuk, R.G. (1977). Motor short-term memory measures as a function of methodology. *Journal of Motor Behavior*, 9, 247-250.
- Marteniuk, R.G., & Roy, E.A. (1972). The codability of kinesthetic location and distance information. *Acta Psychologica*, 36, 471-479.
- Marteniuk, R.G., Shields, K.W., & Campbell, S. (1972). Amplitude, position, timing and velocity as cues in reproduction of movement. *Perceptual and Motor Skills*, 35, 51-58.
- Newell, K.M. (1976). More on absolute error, etc. *Journal of Motor Behavior*, 8, 139-142.
- Pepper, R.L., & Herman, L.M. (1970). Decay and interference effects in the short-term retention of a discrete motor act. *Journal of Experimental Psychology, Monograph Supplement*, 83, (2, Part 2).
- Peterson, L.R., & Peterson, M.J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, 58, 193-198.
- Posner, M.I. (1967). Characteristics of visual and kinesthetic memory codes. *Journal of Experimental Psychology*, 75, 103-107.
- Posner, M.I., & Konick, A.F. (1966). Short-term retention of visual and kinesthetic information. *Organizational Behavior and Human Performance*, 1, 71-86.
- Poulton, E.C. (1973). Unwanted range effects from using within-subject experimental designs. *Psychological Bulletin*, 80, 113-121.
- Poulton, E.C. (1975). Range effects in experiments on people. *American Journal of Psychology*, 88, 3-32.
- Poulton, E.C. (1979). Models for biases in judging sensory magnitude. *Psychological Bulletin*, 86, 777-803.
- Poulton, E.C. (1981). Human manual control. In V.B. Brooks (Ed.), *Handbook of physiology: Section 1, The nervous system*, (Vol. 2, pp. 1337-1389). Bethesda, Maryland: American Physiological Society.
- Roy, E.A. (1976). Measuring change in motor memory. *Journal of Motor Behavior*, 8, 283-287.
- Roy, E.A. (1978). Role of preselection in memory for movement extent. *Journal of Experimental*

- Psychology: Human Learning and Memory*, 4, 397-405.
- Roy, E.A., & Diewert, G.L. (1975). Encoding of kinesthetic extent information. *Perception & Psychophysics*, 17, 559-564.
- Safrit, M.J., Spray, J.A., & Diewert, G.L. (1980). Methodological issues in short-term motor memory research. *Journal of Motor Behavior*, 12, 13-28.
- Schutz, R.W. (1974). Absolute error. *Journal of Motor Behavior*, 6, 299-301.
- Schutz, R.W., & Roy, E.A. (1973). Absolute error: The devil in disguise. *Journal of Motor Behavior*, 5, 141-153.
- Searle, L.V., & Taylor, F.V. (1948). Studies of tracking behavior. I. Rate and time characteristics of simple corrective movements. *Journal of Experimental Psychology*, 38, 615-631.
- Shea, J.B. (1977). Effects of labeling on motor short-term memory. *Journal of Experimental Psychology: Human Learning and Memory*, 3, 92-99.
- Slack, C.W. (1953a). Learning in simple one-dimensional tracking. *American Journal of Psychology*, 66, 33-44.
- Slack, C.W. (1953b). Some characteristics of the "range effect". *Journal of Experimental Psychology*, 46, 76-80.
- Spray, J.A. (1986). Absolute error revisited: An accuracy indicator in disguise. *Journal of Motor Behavior*, 18, 225-238.
- Stamm, C.L., & Kelso, J.A.S. (1978). Reliability and motor memory. *Journal of Motor Behavior*, 10, 15-23.
- Stelmach, G.E. (1969). Prior positioning responses as a factor in short-term retention of a simple motor task. *Journal of Experimental Psychology*, 81, 523-526.
- Stelmach, G.E. (1970). Kinesthetic recall and information reduction activity. *Journal of Motor Behavior*, 11, 183-194.
- Stelmach, G.E. (1974). Retention of motor skills. In J.H. Wilmore (Ed.), *Exercise and sport sciences reviews* (Vol. 2, pp. 1-31). New York: Academic Press.
- Stelmach, G.E. (1982). Memory for movement with emphasis on short-term aspects. In J.A.S. Kelso (Ed.), *Human motor behavior: An introduction* (pp. 117-139). Hillsdale, New Jersey: Lawrence Erlbaum.
- Stelmach, G.E., & Kelso, J.A.S. (1975). Memory trace strength and response biasing in short-term motor memory. *Memory and Cognition*, 3, 58-62.
- Stelmach, G.E., Kelso, J.A.S., & McCullagh, P.D. (1976). Preselection and response biasing in short-term motor memory. *Memory and Cognition*, 4, 62-66.
- Stelmach, G.E., Kelso, J.A.S., & Wallace, S.A. (1975). Preselection in short-term motor memory. *Journal of Experimental Psychology: Human Learning and Memory*, 1, 745-755.
- Stelmach, G.E., & Walsh, M.F. (1972). Response biasing as a function of duration and extent of positioning acts. *Journal of Experimental Psychology*, 92, 354-359.
- Stelmach, G.E., & Walsh, M.F. (1973). The temporal placement of interpolated movements in short-term motor memory. *Journal of Motor Behavior*, 5, 165-173.
- Stelmach, G.E., & Wilson, M. (1970). Kinesthetic retention, movement extent, and information processing. *Journal of Experimental Psychology*, 85, 425-430.

- Thomas, J.R. (1977). A note concerning analysis of error scores from motor-memory research. *Journal of Motor Behavior*, *9*, 251-253.
- Thomas, J.R., & Nelson, J.K. (1990). *Research methods in physical activity* (2nd ed.). Champaign, IL: Human Kinetics.
- Walsh, W.D., Russell, D.G., & Imanaka, K. (1980). Memory for movement: Interaction of location and distance cues and imagery ability. *Acta Psychologica*, *44*, 117-130.
- Walsh, W.D., Russell, D.G., Imanaka, K., & James, B. (1979). Memory for constrained and preselected movement location and distance: Effects of starting position and length. *Journal of Motor Behavior*, *11*, 201-214.
- Yasuyoshi, H., & Naruse, G. (1978). The effect of criterion distance and starting position on the linear-motor recall task. *Research Bulletin of Educational Psychology, Faculty of Education, Kyushu University*, *23*, 1-5.