

## Information-Processing Mediating the Location-Distance Interference in Motor Short-Term Memory

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We reviewed the literature on basic psychological correlates of the well-known phenomenon of the location-distance interference in motor short-term memory (Kerr, 1978 ; Walsh, Russell, Imanaka, & James, 1979). The location-distance interference in motor short-term memory has frequently been demonstrated as an unavoidable interference phenomenon observed in the reproduction of movement location and distance in arm positioning. The most important aspect of this phenomenon is that even when a subject concentrates on a specific cue (i.e., either end-location or distance) the other cue is also coded unintentionally and, as a result, the reproduction movement guided on the basis of the specific cue is unavoidably influenced by the other nonspecific cue. In this review article, we first reviewed the literature on the basic theories and nature of short-term memory, particularly on the limited processing capacity. We then referred to the unlimited, automatic processing in visual-verbal domains, referring to the Stroop phenomenon. Finally, in conjunction with the notion of automatic processing, we examined the possible aspects of information processing which may be responsible for mediating the location-distance interference in motor short-term memory.

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### Introduction

The performance of skilled movement is dependent on the availability of various sources of sensory information and on the use of selected neural mechanisms (see Imanaka & Funase, 1992). Many skilled movements require quite strict spatial and temporal organization of muscular activities, and this organization can be modified and optimized through practice and experience, through the processes of motor learning and memory.

Learning can be thought of as the process of organizing information from various peripheral and central sources into a meaningful structure, favorable to good task performance (Marteniuk, 1976).

Learning, including motor learning, can be viewed as a relatively permanent change in performance (Kerr, 1982), or as a neural change (Eccles, 1977 ; Sage, 1984), resulting from practice or past experience. The processes of learning cannot be viewed directly and must be inferred (indirectly) from changes in behavior (Sage, 1984). A synthetic definition of motor learning proposed by Schmidt (1988) is "... a set of processes associated with practice or experience leading to relatively permanent changes in the capability for responding" (p.346). Any notion of learning also necessarily invokes the concept of memory, as an essential means of storing past experiences. Sage (1984) suggests that one way to under-

stand how motor skills are acquired is to study the memory aspects of motor behavior, since learning obviously requires memory.

With respect to the issues of motor memory, a large number of researchers (Adams & Dijkstra, 1966; Adams, Gopher, & Lintern, 1977; Diewert, 1975, 1976; Diewert & Roy, 1978; Keele & Eells, 1972; Marteniuk & Roy, 1972; Roy, 1977, 1978; Roy & Diewert, 1975, 1978; Roy & Kelso, 1977; Russell, 1978; Stelmach & Kelso, 1973, 1975; Stelmach, Wallace, & McCracken, 1977; Sullivan & Salmoni, 1975) conducted experiments in 1970s to examine the retention characteristics of movement end-location and distance cues, with a major controversy being addressed by several theories for motor short-term memory (Adams, 1971; Kelso, 1977a; Laabs, 1973; Pepper & Herman, 1970; Stelmach, Kelso, & McCullagh, 1976; Stelmach, Kelso, & Wallace, 1975). These theories related to which parameter of limb movement, such as end-location and distance, was the more reliable cue for remembering movements, and were based on the assumption that end-location and distance information were coded independently from each other (Buck, 1982; Diewert, 1975; Frekany, 1978; Gundry, 1975; Hagman, 1978; Hagman & Williams, 1977; Roy & Williams, 1979; Running & Diewert, 1982; Wallace, 1977). In contrast, Kerr (1978) and Walsh, Russell, Imanaka, and James (1979) proposed that the end-location and distance cues were not coded independently, and that recall of either cue was influenced by the other cue, even when subjects were instructed to concentrate only on the specific cue to be reproduced. This resulted in cessation of the earlier debates on the issues of the end-location and distance cues for remembering movements.

For the interference phenomenon between location and distance cues, the robustness of this phenomenon has since been established by Walsh's group (Walsh et al., 1979; Walsh & Russell, 1979, 1980; Walsh, Russell, & Boustead, 1981; Walsh, Russell, & Crassini, 1981; Walsh, Russell, & Imana-

ka, 1980) over various conditions, such as short and long delays, constrained and preselected movements, imagery abilities, and so on. The interference phenomenon in motor short-term memory has also been demonstrated by other researchers, both earlier (Diewert & Roy, 1978; Marteniuk & Roy, 1972; Stelmach & Kelso, 1973) and later (Ashby, Shea, & Howard, 1980; Wrisberg, Millsagle, & Schliesman, 1987; Wrisberg & Winter, 1985). Nevertheless, the underlying mechanisms responsible for this phenomenon are still unclear. In an attempt to account for the underlying mechanisms of the interference phenomenon between movement location and distance cues, we now review the literature on some psychological aspects relevant to this interference phenomenon.

The following sections provide a brief review of the various processes and information-processing stages generally believed by experimental psychologists to underlie the production, control, learning and storage of skilled movement. We first examine the general concepts of memory (i.e., concepts not specific to motor behavior) along with two models: the duplex model and the levels-of-information-processing model. Then, we refer to the basic theories of short-term memory, particularly on the limited processing capacity in the nature of short-term memory as well as on unlimited, automatic processing. Following this, we review the Stroop-type phenomenon as the manifestation of unavoidable automatic processing in either visual, auditory, or verbal domain. Finally, we examine a possible, plausible interpretation in attempting to account for the interference phenomenon in motor short-term memory, in conjunction with the automatic processing. The focus in these sections is generally on theoretical, hypothesized concepts or mechanisms of motor behavior rather than on the demonstrable anatomy and physiology of the motor system.

### General Concepts of Memory

Human memory is frequently conceptualized as

an information-processing system, which can be divided into a series of stages. Three principal storage structures are usually invoked: a sensory register (or short-term sensory store), short-term memory and long-term memory (Atkinson & Shiffrin, 1965, 1971; Klatzky, 1980; Shiffrin & Atkinson, 1969). In the sensory register, incoming stimulus information is believed to be precisely retained in a raw, sensory form (i.e., as a literal representation of the stimulus input). Such information however decays very rapidly, as in about 1 sec for visual stimuli (Sperling, 1960). It is assumed that during this brief period, the raw representation of the stimulus can be recognized or encoded and passed on to the next stage in the system, the short-term memory (Klatzky, 1980). In short-term memory, it is believed that information can be retained again for a relatively short period, generally not longer than 60 sec (Melton, 1963). However, information can be maintained in short-term memory much longer through the use of a holding process, or rehearsal. Rehearsal can prevent the information from decaying and make it relatively permanent, allowing information to be moved on to long-term memory (Klatzky, 1980).

Such a model involving two separate memory structures (i.e., short-term and long-term memory) is generally known as the duplex model. Although the duplex model has been widely accepted, largely because it can easily accommodate a large amount of the existing memory research, it has also been suggested that the assumption of two separate memory structures may not necessarily be needed to interpret the memory processes (e.g., Wickelgren, 1973). Rehearsals in short-term memory lead to establishing memory codes in long-term memory, and long-term memory contributes greatly, through the process of recognizing an incoming stimulus as a known pattern, to the encoding in short-term memory. Klatzky (1980) has pointed out that some researchers have sometimes distorted the notion of short- and long-term memory far beyond

recognition of the original conception in trying to fit complex memory operations into a duplex framework. In spite of these criticisms, the duplex theory has been believed to be a useful and convenient model of memory, particularly in distinguishing between those memory representations which are currently "in mind" and those items of knowledge which are in storage and in need of retrieval (Klatzky, 1980; Solso, 1979).

One alternative viewpoint of memory is the levels-of-processing theory of Craik and Lockhart (1972). The fundamental assumption of this model is that an incoming stimulus can be processed in terms of various different properties of the stimulus, such as its physical, acoustic, or semantic characteristics, and that these various types of processing can be thought to be ordered in terms of the depth, or elaborateness, of the analysis performed on the incoming stimulus. A stimulus can be processed in terms of different properties at various depths (or levels) of processing. The depth or level of processing in encoding is hypothesized to directly affect recall performance such that recall is directly proportional to the level of processing done on the stimulus during encoding. It is predicted that deeper processing results in more stable codes in memory (Craik & Lockhart, 1972; Craik & Tulving, 1975). Although the details of the levels-of-processing model have often been modified (e.g., Jacoby, Bartz, & Evans, 1978; Lockhart, Craik, & Jacoby, 1976) or criticized (e.g., Baddeley, 1978), this theory has a strong following. Klatzky (1980), for example, has suggested that the levels-of-processing approach has an advantage in distinguishing between deep and shallow processing in memory, and that this approach can also present an expanded view of active processing of stimuli and its relationship to long-term retention and retrieval.

Since learning must involve all of the memory processes described above, the two terms of learning and memory have often been used in combination (Eccles, 1977; Sage, 1984). The process of per-

ception is also, in some respects, functionally inseparable from memory. In the process of perception, stimuli are received from the environment in the sensory register, and then recognized as a known sensation through comparison of the current information with that stored in long-term memory. If one is asked to provide an immediate or delayed response following the presentation of a stimulus, memory, particularly short-term memory, must be involved in both the perceptual and response processes (Walsh, 1980).

### **Short-Term Memory and its Limited Processing Capacity**

The majority of short-term memory research has focused upon capacity limitations in the ability of humans to process and store information. Key limitations include constraints imposed by the time over which information can be retained, and imposed by the amount of information that can be held simultaneously (Klatzky, 1980). The span of short-term memory is believed to be limited to seven plus or minus two chunks (Miller, 1956) or groups of information (Klatzky, 1980). Where significant amounts of new information are presented either simultaneously or in rapid succession, such limitations may cause the loss of initially encoded information, resulting in forgetting.

#### *Forgetting*

Forgetting is thought to be the result of either passive decay or interference. Passive decay implies that the strength of the memory trace simply decreases with the passage of time. Alternatively, the memory trace may decline in strength because new material enters short-term memory and interferes with the storage or memory code of the preceding material.

Brown (1958) showed that even a delay of a few seconds between the presentation of visual stimuli and their recall produces considerable forgetting. This forgetting was especially pronounced when the subject was required to perform an additional activ-

ity (called a destructor or interpolated task) during the retention period. The destructor task was used to prevent subjects from rehearsing items to be recalled, and was assumed not to interfere with the items because materials presented in the destructor task did not need to be remembered for recall. Peterson and Peterson (1959) also employed a destructor task to prevent rehearsal; in their case, the task was one of counting backwards from a given three-digit number. Capability for the recall of a three-consonant sequence showed a marked and rapid decline as the retention interval was increased from 3 to 18 sec. Such loss of information from within the Brown-Peterson paradigm was, therefore, attributed to passive decay.

Keppel and Underwood (1962), however, attributed the rapid short-term forgetting, such as reported by Peterson and Peterson (1959), to changes in the amount of proactive inhibition arising from preceding trials. Keppel and Underwood showed no forgetting during the 18-sec retention interval on the first trial, but did demonstrate rapid forgetting similar to that observed by Peterson and Peterson (1959) on all subsequent trials. This finding supported an interference explanation (i.e., preceding trials interfered with the following trials) for short-term forgetting, an explanation also subsequently supported by Waugh and Norman (1965). Reitman (1971) also showed no forgetting, rather complete recall, in recalling words after a 15-sec retention interval. During retention intervals, the subjects were required to respond to a tone which occurred in a background of white noise. This destructor task was presumably difficult enough to prevent rehearsal, and should not have interfered with the three words which were required to be held in short-term memory. Reitman's findings were confirmed and expanded by Shiffrin (1973), who demonstrated no decline in recall performance during much longer (up to 40 sec) retention intervals interpolated with a signal-detection task. These studies thus provided no evidence for decay as a cause of the forgetting in

short-term memory. More recently, however, evidence for the decay theory has again been reported by Reitman (1974) and Shiffrin and Cook (1978).

In contrast to both the decay and interference explanations of forgetting, Posner (1967) has argued, using the "acid-bath" analogy, that the amount of corrosion of metal (analogous to forgetting) is determined by both the strength of the acid (i.e., interference) and the time (decay) over which the acid has to work. It has thus been believed that both decay and interference may be operating in the forgetting in short-term memory (Klatzky, 1980; Solso, 1979).

#### *Limited Processing Capacity*

As mentioned previously, short-term memory is limited in its capacity to process information. This limited capacity is not restricted to any particular processing stage, but is a characteristic of many stages of the information-processing system. This limited capacity is frequently termed attention (Klatzky, 1980). The term attention has been actually used in the literature of experimental psychology in at least three different contexts (see Kahneman, 1973; Marteniuk, 1976), namely, (a) attention as alertness, (b) attention as selective attention and (c) attention as a limited processing capacity. Alertness can be thought of as "a state of the central nervous system such that it is 'ready' to receive and process information at an optimal rate" (Marteniuk, 1976, p.40). According to the latter context (attention as a limited processing capacity), attention involves, among other things, the problem of selecting only pertinent information for processing (Ishiguchi, 1983), and this aspect of attention is usually referred to as selective attention.

A number of studies have attempted to identify the mechanisms underlying selective attention (e.g., Broadbent, 1958; Cherry, 1953; Deutsch & Deutsch, 1963; Norman, 1976; Treisman, 1969). Broadbent (1958), for example, proposed a theoretical model in which selective attention was conceived to act like a filter allowing only a single channel of informa-

tion to be processed, while blocking completely the processing of all other information. Norman (1976) proposed a model of pattern recognition and attention involving both early and late processing of information. All incoming patterns of visual stimuli were conceived to activate relevant codes in long-term memory to some extent (early processing), with selective attention then corresponding to the full activation of the codes for only some selected patterns. It was these patterns which were then believed to be consequently recognized (late processing). Neisser (1967, cited in Neisser, 1976) called this early processing in pattern recognition preattentive processing and the late processing, or full recognition, attention. Pre-attention was believed to involve strictly parallel, non-capacity-limited processing, whereas attention implied serial, capacity-limited processing. Although these early models, such as Broadbent's filter model, have been challenged by several findings and are now thought to be incorrect (Schmidt, 1988), the human information-processing system is nevertheless still generally thought to involve two distinct kinds of processing: automatic processing, which is thought to rely upon non-capacity-limited processes, and attention-demanding or controlled processing, which corresponds to full recognition or capacity-limited processing (see Klatzky, 1980).

#### **Automatic Processing :**

##### **Unlimited Processing Capacity**

The notion of controlled and automatic processing has been popularized by researchers in cognitive psychology (e.g., Posner & Snyder, 1975a, 1975b; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automatic processing is defined as fast parallel processing that is not limited by short-term memory, whereas controlled processing is relatively slow, mentally demanding, and believed to require considerable involvement of short-term memory (Gopher & Donchin, 1986). According to Schmidt (1988), controlled processing is slow, attention

-demanding, serial in nature, and strongly volitional, and accordingly, processing of this type can be easily stopped or avoided altogether. In contrast, automatic processing is fast, non-attention-demanding, can occur in parallel with other simultaneous processing operations, and is not volitional. Accordingly, this processing is often unavoidable and cannot be consciously stopped or controlled.

Neumann (1984) has identified three aspects of automatic processing which have typically been used by researchers as criteria for determining automaticity. These three aspects are: (a) automatic processes operate without capacity, and thus, neither suffer nor cause interference; (b) automatic processes are under the control of stimulation rather than the intentions (strategies and planning) of the person (i.e., they are data-driven rather than consciously driven); (c) automatic processes do not necessarily give rise to conscious awareness. However, Neumann has argued that at least two of these assumed properties of automatic processing may be inappropriate. First, Neumann contends that most processes considered to be automatic are not generally free from suffering or producing interference, although interference-free processing may be found with well-practiced skills if certain task conditions are fulfilled. The second concern is that some automatic processes are not independent of a person's current intentions and direction of attention. Many apparently automatic processes may occur (such as is demonstrated by the Stroop phenomenon) which are at odds with the explicit intention of the performer. In such cases, the automatic processes can be thought to depend on an intention, although they do not exactly conform to it. Thus, the concept of automaticity is not perfectly clear and is operationally difficult to define (Schmidt, 1988).

#### **The Stroop Interference and Unavoidable Automatic Processing**

One early demonstration of unavoidable automatic processing was provided by the Stroop (1935)

color-word phenomenon. This phenomenon can be observed in tasks requiring subjects to name the colors of inks used to print words. The usual result is that subjects are slower to name the colors when the word means a color name that is different from the ink used to print it (e.g., the word "RED" printed in the color green) than when the word means the color name of the ink (e.g., the word "RED" printed in the color red). That is, the task-irrelevant aspects or parts of the stimulus (the word meaning) cause interference despite the subject's attempts to ignore them. Analogous effects have been obtained in numerous variations of the Stroop test: for example, the counting of the number of stimulus items when the items themselves are digits and the digits presented conflict with the number to be counted (Morton, 1969); the judgement of the pitch of incongruent stimulus words "high" at low frequency and "low" at high frequency (Cohen & Martin, 1975); the judgement of speaker gender of the incongruent stimulus words "man" in a female voice and "girl" in a male voice (Green & Barber, 1981, 1983).

The Stroop effect has been thought to occur because both word and color (or other physical dimensions of the stimulus) are processed at about the same time, although the exact mechanisms producing the obvious interference still remain unclear (Naish, 1985). At least three possible locations for the mechanisms responsible for the Stroop phenomenon have been proposed in the literature. First, the interference may occur early in the analysis of the printed stimulus, or in the encoding processes (Hock & Egeth, 1970). Second, it may occur at a late stage, perhaps in the response output phase (Morton, 1969; Morton & Chambers, 1973). Information about the word's meaning may reach the output buffer prior to information about the word's color simply because word-reading rather than color recognition may be an automatic process (Posner & Snyder, 1975a, 1975b). The third possibility is that the interference may occur in some middle stage of processing, due to an overlap between the con-

ceptual codes used for word meaning and for color (MacKinnon, Geiselman, & Woodward, 1985; Naish, 1985; Seymour, 1977; Stirling, 1979).

The Stroop effect has been often explained by the relative speed hypothesis (or the race model), in which the process for word-reading, which is faster than the process involved in color-naming, is proposed to cause interference in naming the color of ink when the color is incongruent with the meaning of the word. However, the results of some recent studies suggest that this simple race model may be inadequate. Dunbar and MacLeod (1984) examined the Stroop interference by using geometrically transformed words (i.e., words presented upside-down and backwards) so that the reading of the words was made more difficult and consequently took a longer time than the naming of the colors. The results showed that even when reading a color word was considerably slower than naming the color of the ink in which the word was printed, the Stroop interference persisted virtually unaltered. This result suggests that the relative speed model does not provide an adequate overall explanation of the Stroop phenomenon. Alternatively, Dunbar and MacLeod have proposed that since the number of possible responses in the ink-naming task is only five (red, blue, green, yellow and orange), the threshold for activation of a particular response may be lowered prior to stimulus presentation, resulting in fast recognition of the transformed color words. Dunbar and MacLeod suggest that the interference observed in the Stroop phenomenon is not due to the limited capacity of the response buffer, but is rather a consequence of the amount of priming that each possible response receives.

An alternative explanation of the Stroop effect is based on the notions of cerebral hemispheric specialization. The starting assumption is that the left hemisphere processes information both visually and vocally, whereas the right hemisphere processes information on a visual basis alone (Davidoff, 1976; Dimond & Beaumont, 1972; Pennal, 1977). Schmit

and Davis (1974) examined the Stroop effect by manipulating both the visual field for the presentation of the color-words and the hand used to respond. When subjects responded with the left hand, a greater Stroop effect occurred when an incongruent color-word was presented in the right visual field (i.e., left hemisphere processing), but no interference occurred in the left visual field (i.e., right hemisphere processing). When the color-word was presented in the left visual field, the color component may have been processed in the right hemisphere, whereas the word component may have been transferred into the left hemisphere to be processed, consequently avoiding any attentional conflict. In contrast, when the stimulus was presented in the right visual field, both the color and the word components may have been processed in the left hemisphere at the same time, and thus a greater Stroop effect occurred. This finding suggests that the Stroop effect may reflect cerebral hemisphere specialization for the processing of color and word information. Likewise, Hatta (1981) tested the Stroop effect by presenting Japanese kanji stimuli as the color-words in either the left or the right visual field. Kanji is essentially non-phonetic, logographic symbol and is thought to be processed in the right hemisphere when presented individually (Hatta, 1977, 1979; Sasanuma, Itoh, Mori, & Kobayashi, 1977). Hatta (1981) reported that a larger Stroop effect occurred in the right hemisphere than the left one. His interpretation was that the larger interference occurred in the right hemisphere because both color and kanji stimuli were processed in the same hemisphere at the same time. This finding is in agreement with those of Biederman and Tsao (1979), and is also consistent with the findings of Cohen and Martin (1975), who observed different auditory Stroop effects for processing tasks using the left and right hemispheres. Taken together, this evidence suggests that the Stroop phenomenon may be a direct reflection of hemispheric specialization, and may possibly have some potential as a means of

exploring hemispheric specialization in various dimensions, at least for visual and auditory tasks.

If it is the case that the Stroop phenomenon is a direct reflection of hemispheric specialization for information processing or a consequence of the amount of priming that each possible response receives, the Stroop-type phenomenon may well be expected to arise for different modalities, such as vision and audition. This is because the hemispheric specialization and priming are generally assumed to be defined as modality-free mechanisms. Furthermore, the Stroop phenomenon involves unavoidable automatic processing of unattended stimuli available from either visual or auditory material. The Stroop-type phenomenon is, therefore, assumed to be caused by more general, modality-free mechanisms causing some interference or conflict among information processing of two or more different parameters available from given material or a given event. Such general mechanisms may involve attention-demanding and automatic processing of available information, causing conflicts between both types of information processing. This view suggests that the Stroop-type phenomenon may occur in the kinesthetic modality as well, although no study has yet attempted to examine this possibility.

**The Location-Distance Interference  
in Motor Short-Term Memory  
as a Manifestation  
of Unavoidable Automatic Processing**

It may well be possible to link the above-mentioned likely mechanisms underlying the Stroop-type phenomenon to the well-known phenomenon of the interference between kinesthetic location and distance information in motor short-term memory (Kerr, 1978; Walsh et al., 1979). The location-distance interference in motor short-term memory has been found to occur unavoidably in the reproduction of either location or distance cues available from a preceding standard (or criterion) movement. In the experiments of Walsh et al. (1979),

subjects were required to reproduce either the end-location or the distance moved during a criterion movement. When the starting position of the reproduction movement was changed from that of the preceding criterion movement, reproduction performance was affected by unattended cues, namely, the distance moved on the criterion movement when the end-location of the criterion movement was to be reproduced and end-location of the criterion movement when movement distance was to be reproduced. This resulted in a systematic pattern of undershooting and overshooting in movement reproduction arising as a function of the shift in starting position even when the subjects concentrated on a single movement cue, either the end-location or the distance moved on the criterion movement.

The effect of unattended cues on reproduction performance, or the systematic undershooting-overshooting pattern in movement reproduction, has since been confirmed in a wide range of arm positioning experiments (Imanaka, 1989, 1991; Imanaka & Abernethy, 1990, 1991, 1992a, 1992b; Walsh, Russell, & Boustead, 1981; Walsh, Russell, & Crassini, 1981; Wrisberg & Winter, 1985). Furthermore, Imanaka (1989) and Imanaka and Abernethy (1991) have recently confirmed the systematic undershooting-overshooting pattern in movement reproduction to be a phenomenon that is specific to motor short-term memory and not an artifact of any learning or central tendency effects gradually arising as an averaging effect throughout the course of typical motor short-term memory experiments (cf. Poulton, 1973, 1975, 1979, 1981). The evidence collected thus far has, therefore, generally supported the interference hypothesis proposed by Walsh et al. (1979).

With respect to the underlying causes of the systematic response bias pattern, it has recently been found that the systematic undershooting-overshooting pattern in movement reproduction does not appear to be affected by changes in actual kinesthetic signals arising from criterion and reproduc-



tion movements (Imanaka & Abernethy, 1992b) or by changes in the availability of conscious feedback information (Imanaka & Abernethy, 1990) during the execution of criterion and reproduction movements. The interference between location and distance information, therefore, seems likely to occur not at the level of somewhat lower, unconscious sensory or perceptual motor systems but, rather, within a more abstract, cognitive level of information processing. Cognitive processing has conventionally been advanced by earlier researchers (Kerr, 1978; Russell, Walsh, & Taylor, 1982; Walsh, 1980, 1981; Walsh et al., 1979, 1980; Wrisberg & Winter, 1985) as the principal source of the interference between location and distance cues during encoding. This line of interpretation of the underlying mechanisms of the location-distance interference in motor short-term memory has recently been supported by Imanaka and Abernethy (1992a), who proposed the notion of automatic and controlled processing (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) as a plausible explanation to account for the underlying mechanisms of location-distance interference in motor short-term memory. Such a view is generally consistent with the explanations advanced to account for the Stroop phenomenon as it was observed for visual and auditory materials, which may also provide insight into the origins of this kinesthetic interference in motor short-term memory (cf. Dyer, 1973).

Although there are some difficulties, at present, in interpreting the pattern of undershooting and overshooting in movement reproduction in terms of a simple dichotomy between automatic and controlled processing, there are sufficient similarities in the nature of automatic processing to the phenomenon of the systematic undershooting-overshooting pattern in movement reproduction to warrant further consideration. The systematic undershooting-overshooting pattern in movement reproduction may be caused by the interfering effects of unattended information—information that may be processed in

parallel with the essential information about the specific cues to be reproduced. This additional cue processing is not volitional, that is, it is unavoidable. Imanaka and Abernethy (1992a) have recently demonstrated that when subjects are required to attend to the non-specific cues in reproducing the specific movement cues (in other words, the non-specific cues are subjected to controlled processing), the typically observed response bias pattern disappeared. Thus, it is possible to interpret the phenomenon of the interference between location and distance information in movement reproduction in conjunction with Shiffrin and Schneider's concept of controlled and automatic processes, as well as to the interpretation advanced to account for the Stroop phenomenon.

In conclusion, the reproduction of movement may not be based on a single movement cue, as several earlier researchers (e.g., Diewert & Roy, 1978; Jones, 1974; Kelso, 1977a, 1977b; Laabs, 1973; Russell, 1976) have proposed, but may rather be based on an integration of relevant sources of movement information such as location and distance (Kerr, 1978; Walsh et al., 1979). However, this integration may not simply be taken place between location and distance information, as Walsh et al. have concluded. Rather, it may be that the interference between location and distance information arises from more general cognitive aspects of perceptual-motor control and memory, and that the explanation of this interference necessitates consideration of global interactive effects of the automatic and controlled processing, such as that in the general interpretation adopted in explaining the Stroop phenomenon.

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