STIMULUS DETECTION AND IDENTIFICATION IN RESPONSE PROGRAMMING

by

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ABSTRACT

The control of movement has been a traditional concern in the psychomotor domain. In order to explain how the mechanism(s) underlying movement control function, the effects that numerous movement parameters (e.g., target amplitude, movement velocity, etc.) have on the motor system have been examined. This type of investigation led to a peripheral-central motor control dichotomy. Recent interest, however, has shifted from the mode of motor control to movement preparation or motor programme construction. Accordingly, the partial advance information paradigm was refined and the movement precuing technique was developed as a method of studying the movement preparation process. Several theoretical considerations have not been addressed in the movement precuing approach. As such, the present studies were undertaken in an attempt to gain a more complete understanding of the motor programme construction process. More specifically, the movement precuing technique may be subjected to two major criticisms. The first stems from the use of coloured circles as reaction stimuli. The coloured circles may not have been highly compatible with their associated responses. If not, a non-motor decision (stimulus-response translation) confounded the reaction time

measures. Since reaction time was considered to reflect the response programming process, any theoretical interpretations drawn from the research must be questioned. Secondly, before any movement preparation may begin, the stimulus must be detected and identified. Therefore, programming time estimates may have been confounded with stimulus detection/identification time. If further progress is to be made in the comprehension of response programming, the non-motor contaminating factors need to be controlled. Therefore, the present investigation was undertaken to provide high stimulus-response compatibility and separate estimates of stimulus identification and response preparation times.

Since the movement precuing approach necessitated that all movements be performed without visual feedback, Experiment 1 was designed to determine if Fitts' Law remained unchanged for non-visually guided movements. It is possible that the preparation of a response may not be completed before movement initiation. Changes in movement time may signal incomplete response preparation during the reaction time. If this is the case, the relationships outlined by Fitts' Law must be examined in the absence of vision. When these relationships have been determined, conclusions regarding response preparation after movement initiation may be made. In Experiment 1, subjects performed a reciprocal tapping task with three different indices of difficulty. A statistically significant correlation of .724

was found between movement time and index of difficulty. The results indicated that the relationships between movement time, target width, and movement amplitude were maintained for movements without visual feedback.

Experiment 2 altered the movement precuing technique to furnish separate estimates of stimulus identification and response preparation times. Stimulus identification time for direction was estimated to be 202 msec and response preparation time 22 msec. The times for extent were 210 msec and 2 msec respectively. Further, a response programming analysis revealed a differential programming effect between direction and extent. The mean RT for direction was 224 msec . Extent on the other hand had a much shorter mean RT at 212 msec. With respect to the different values of a feature, no differential programming effect was noted. The results from the first experiment were employed in a movement time analysis so that any closed-loop aspects of the task could be identified. The results from both the identification and programming analyses were discussed with reference to the motor programme construction process.

Dedicated to my Father,

I wish you were here to share in this moment

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INTRODUCTION

The origins of psychomotor learning and performance research, while being difficult to identify, are also extremely diverse in nature (Irion, 1969; Singer, 1975). In spite of the diversity, research conducted on motor skills has been traced back to the nineteenth century (e.g., Bryan & Harter, 1897; Donders, 1869; James, 1890; Woodworth, 1899). Accordingly, three early traditions have contributed significantly to the development of learning and performance theory since the beginning of this century. The Connectionist or stimulus-response (S-R) tradition believed the conditioned response was the basic unit of learning (Hull, 1943; Pavlov, 1927; Skinner, 1931; Thorndike, 1931). Complex behaviour was believed to be a chaining together of the conditioned responses (S-R bonds). The second tradition, although concerned with S-R bonds, placed the importance on the temporal relationships between the stimulus and response (Watson, 1916). This Contiguity (Behaviourist) tradition considered all other factors as being irrelevant to the S-R relationship. One of the problems often inherent with S-R theory is the failure to account for cognition between the stimulus and response. Since man is complex thinking organism, cognition must play a role in any learning or performance theory. The Cognitive tradition has based its theories on the preceeding premise (Koffka, 1935; Tolman, 1948).

The research produced by each of these traditions must be complemented for their additions to the understanding of behaviour. The inability of any single theory to explain differing results in the study of motor skills prompted investigators to take an information-processing (performance) approach to explain the underlying mechanisms of behaviour. At this point, it is necessary to make the distinction between learning theory and performance theory. Performance theory treats a subject as an information processor composed of several different mechanisms designed for the detection, recognition, storage and decision of appropriate action based on incoming information (Bernstein, 1967; Marteniuk, 1976a; Massaro, 1975; Welford, 1976). The study of human performance provides an understanding about the current state of an individual's information processing capacity while, learning theory has attempted to determine how these mechanisms change with time and practice. The information-processing approach assumes the performer's central nervous system actively operates on the sensory inputs it receives (Bernstein, 1967; Marteniuk, 1976b). The input, once transformed, is passed on to subsequent stages for further processing.

Figure 1 represents, in diagramatic form, a set of processes which are hypothesized to underly human performance.

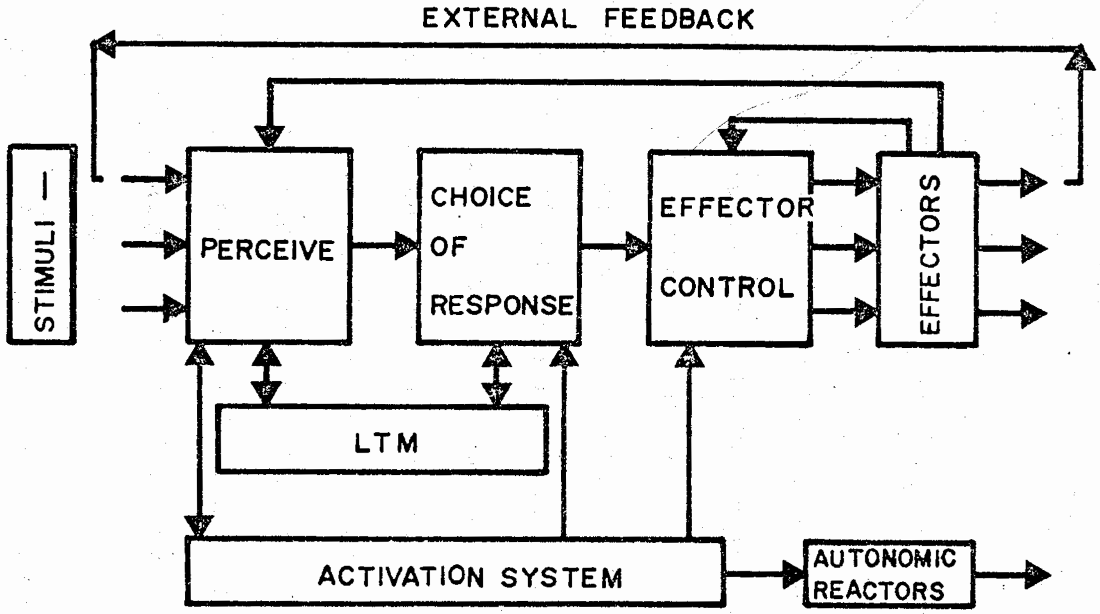

Figure 1. A schematic representation of the human sensory-motor system (adapted from Welford, 1976).

While other processes have been proposed, three major central mechanisms involved in the processing of environmental stimuli have been identified here. These deal with perception, the integration of perception into the decision of appropriate action, and the organization and coordination of the action (Fitts & Posner, 1967; Keele, 1973; Marteniuk, 1976a; Sternberg, 1969; Welford, 1976).

Contemporary research has concentrated primarily on the perceptual and decision mechanisms. The perceptual mechanism organizes and classifies sensory information according to input specifications and past experiences or memory (Bernstein, 1967; Marteniuk, 1976a; Welford, 1976). Information regarding the perceptual experience is transmitted to the decision mechanism where, a plan of action is selected to fulfill the required goal. Reaction time has been the dependent measure most frequently associated with the investigation of perception and decision. Factors that produce a delay in performance, as measured by reaction time, are attributed to the limitations of one or both of these processes.

The same rationale may be applied to the response or effector mechanism. Knowledge about the operation of this mechanism remains relatively incomplete. The effector mechanism, which has received the specified plan of action, is believed to select, organize and construct the required motor commands (Bernstein, 1967; Welford, 1976). In order to understand motor command structuring in the effector mechanism, the different types of motor control must be distinguished (e.g., open vs closed-loop control). Open-loop or programmed motor control is control in which the response commands are prepared before a movement sequence begins and, the movement sequence, once started, is carried out uninfluenced by peripheral feedback (Keele, 1968; Kelso & Stelmach, 1976; Welford, 1976). Feedback, either interoceptive or exteroceptive[1], is a prerequisite in a closed-loop or peripheral control system. Closed-loop control is a self-regulating system as deviations from the intended movement, signalled by feedback, are corrected automatically (Adams, 1971, 1976). In general, studies developed to inspect the effector mechanism fall into the closed-loop or peripheral control classification. Although recent research has questioned effector operation in programmed (central) motor control, methodological problems appear to have hindered the progress of research in this area (e.g., simple reaction time, stimulus-response compatibility). An understanding of this process is a necessary prerequisite for the total comprehension of human motor behaviour.

The major objective of this thesis will be to develop an understanding of motor command structuring by the effector

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[1] Feedback classified as interoceptive refers to movement generated feedback coming from within the body (e.g., muscle spindles, joint receptors). Exteroceptive feedback refers to externally supplied information about a movement (e.g., vision, audition).

mechanism in programmed control. A second, and perhaps equally important, goal is the revelation of a new technique for the estimation of stimulus detection and recognition time. Keeping these in mind, the following sections will briefly discuss the current theories of movement control, task parameters requiring programming, and the different techniques employed to demonstrate response preparation. This review will synthesize the results from several areas of research and provide the basis for the proposed experimentation.

Chapter 2

REVIEW OF LITERATURE

Concepts of Movement Control

Theories on movement production or motor control have generally been classified under two distinctive headings; the first based on peripheral feedback and the second based on central factors. A brief review of these different modes of motor control is necessary at this point. Consequently, the emphasis in the following review will be placed on the differentiation of the two theoretical positions while demonstrating the necessity for central control at some level of movement production.

A peripheral or closed-loop system of control is built on the premise that three key elements are present in the central nervous system (Adams, 1976; Chase, 1965; Sokolov, 1969). A closed-loop system requires feedback, an error detection mechanism, and an error correction mechanism (Adams, 1976). Movement control is a result of the central nervous system receiving feedback so that the ongoing response can be compared with a reference (e.g., perceptual trace). If an error is detected, it is corrected to minimize the deviation between the current state of the response and the desired response output (Adams, 1971, 1976; Keele, 1968; Klapp, 1978). Again, a closed-loop system is self-regulating since these compensations for discrepancies from the reference occur automatically.

The fact remains, however, that even in a closed-loop system, a movement must be retrieved from storage or prepared before initiation is possible (Adams, 1976). To this end, the processes involved up to the point of movement initiation must be open-loop. Even though response preparation must be open-loop, closed-loop theories give an excellent explanation of feedback based movement corrections. Nevertheless, closed-loop control advocates cannot escape this argument or some version of this argument. Therefore, a closed-loop system cannot account for the total control of movement. As such, programmed or open-loop control becomes increasingly more important.

Feedback, a prerequisite for closed-loop control, is deemed unnecessary for the preparation of movement in programmed or open-loop control systems (e.g., Kelso & Stelmach, 1976). It is assumed that the higher structures of the central nervous system already possess all the information necessary for response programming. Programmed or open-loop control then, is control in which the response commands are prepared before a movement sequence begins. The motor programme, once started, is carried out uninfluenced by peripheral feedback (Keele, 1968; Kelso & Stelmach, 1976; Welford, 1976).

Two possibilities exist in explaining how movement commands are available before movement execution. First, the complete set of commands may already be stored in long-term memory and only retrieval is required before execution. In contrast, only generalized plans of action are stored, while, retrieval of this plan and the ensuing structuring of commands are required in advance of movement initiation (as reflected in programming times). While the first choice appears to be extremely plausible on the surface, behavioural research has refuted this alternative. Behavioural research on response programming has demonstrated choice reaction time effects attributed to programming fail to dissipate even in well learned responses (Klapp, 1974, 1976; Rosenbaum, 1978). If long-term memory was the mediator of response programming then the choice reaction time effects would eventually disappear with practice. Since programming takes time, long-term memory has encoded the response information into a form which is not readily accessible for programming (Klapp, 1976, 1977). Clearly, another explanation is warranted. The second hypothesis is the one accepted here and it seems to have a sound theoretical base in Schmidt's (1975) Schema Theory of motor skill acquisition (further explanation may be found in a subsequent section). Futhermore, several assumptions underlying an information-processing approach of motor performance are in accordance with this hypothesis.

The effector mechanism noted in the information-processing model in Figure 1 is hypothesized to have several functions. First, the motor commands associated with the selected plan of action must be organized into a sequential order (Bernstein, 1967; Welford, 1976). Second, the motor commands need to be completed according to the task requirements. Finally, the response must be initiated. These functions require the plan of action (motor programme) to be incomplete. Open-loop control, for at least the first portions of a movement, is an underlying assumption of the information-processing approach.

Hybrid systems of motor control are also possible. Both feedback and programmed control operate in a hybrid system (Keele, 1968; Keele & Summers, 1976; Klapp, 1978); that is, the first segment of a movement is under programmed control and, all subsequent segments are dependent on the feedback from the preceeding segment. Nevertheless, some portion of the movement must be programmed. Programmed or open-loop control then, has an important role in human motor behaviour. As such, the evidence for open-loop control requires careful consideration.

Historical Background

In order to experimentally verify the concept of programmed control, two different approaches have been employed. The first, which emphasizes the lack of feedback criterion, was first proposed by Lashley (1917). Lashley devised the motor programme as an explanation for accurate motor control in a patient who had no afferent input due to a gunshot wound of the spinal cord.

Lashley (1951) reaffirmed his position on central control via a motor programme although, experimental evidence for his position was minimal.

Since that time, numerous studies have sought to support Lashley's (1951) position within this lack of feedback framework. The techniques commonly associated with this approach are deafferentation and rapid movement. Both attempt to eliminate the use of feedback and yet, both are not without their difficulities.

Many studies have demonstrated that movement sequences are maintained after surgical removal of kinesthetic feedback in animals. Wilson (1961) severed all the afferent nerves, which send information about the wingbeat, in a locust. The pattern of wingbeats remained while, the overall rate of beating had slowed. Wilson (1961) concluded that these results could only be explained by central control. In a similar experiment by Nottebohm (1970), the afferent nerves from a bird's vocal and auditory systems were cut. Nottebohm reported that the bird's song still remained. Further, one side of the hypoglossal nerve innervating the vocal system was also severed. Upon the loss of these efferent nerves, portion's of the bird's song dropped out. The segments of the song which were possible stayed in the proper time sequences. Again, programmed control was ruled the only explanation since missing kinesthetic and auditory feedback was not necessary for the generation of the remaining portions of the song. Konishi (1965), after deafening young birds exposed to adult song, found the song pattern continued to develop with no decrements in performance. If feedback was required for the song pattern, performance would have been severely hampered. Konishi (1965) concluded that some type of central programme was used to generate the song.

Since motor control in animals far down the evolutionary scale may be extremely different than that of humans, experimentation on higher order animals, such as monkeys, has been conducted (e.g., Bossom & Ommaya, 1968; Mott & Sherrington, 1895; Taub & Berman, 1968; Taub, Perella, & Barro, 1973; Twitchell, 1954). The problem with the majority of these studies is the failure to account for visual feedback. Frequently, visual feedback may be substituted for kinesthetic feedback and provide guidance for the deafferented limbs. The visual guidance problem was resolved when Taub et al. (1973) deafferented and blinded neonate monkeys. Reasonably accurate and coordinated performance was still possible in several activities after birth. Although vision was removed, several researchers have questioned Taub's deafferentation process (e.g., Bossom and Ommaya, 1968); the criticism being that a few afferent fibers may have remained intact. Even so, the results of surgical removal of feedback in higher order animals cannot be discounted since converging research regularly points to the central control of movement. As much as these results indicate open-loop control, animal functions may be different than that of humans.

Obviously, deafferentation in humans cannot be performed. Thus, different approaches, such as the pressure cuff (nerve compression block) and Xylocaine nerve block, have emerged. Sensory feedback below the point of application of a pressure cuff is assumed to be cut off due to the occluded blood supply (Kelso, Stelmach & Wanamaker, 1974; Lazlo, 1966; Matthews, 1974) while, the motor nerves are believed to be unaffected. Interpretive problems have appeared with this type of experimentation (e.g., Kelso, Stelmach & Wanamaker, 1974; Kelso, Wallace, Stelmach & Weitz, 1975). Kelso et al. (1974) tested the ulnar and median motor nerve conduction velocities and the amplitude of muscle action potentials above the point of application of the pressure cuff. Both the velocity and action potential amplitude showed extreme decrements. Thus, motor impairment was a confounding variable with this technique. The Xylocaine nerve block suffers from a similar problem since the experimenter cannot control the anaesthetic from spreading to motor nerves. Provins (1958) for example, discovered that there was a small decrement in finger tapping with this technique and claimed support for the notion of central motor control. Motor nerve impairment could also be a confounding factor in the Xylocaine nerve block. Nevertheless, the trends suggest that programmed motor control is viable.

Another method of rendering feedback useless is rapid movement. The rationale behind this approach is that the response is completed before any feedback associated with the movement can be of any value for corrections. Behavioural studies have reported the time required to react to kinesthetic stimuli was approximately 100 msec or greater (Glencross, 1976; Keele, 1968). Evarts and Tanji (1974), however, have shown that monkeys make corrections in 30-40 msec. These appear to be spinal reflexes while long-loop corrections require approximately 80 msec. From these times, one would assume that corrections made at the spinal level are not under cognitive control. The motor programme must contain a form of information that allows large deviations from the intended response to be altered at the spinal level. Long-loop corrections are thought to be based on proprioceptive information (Evarts & Tanji, 1974). It appears as though the majority of the studies wishing to eliminate feedback through rapid movement may have had movement duration times which were too lengthy. Although these studies do have procedural difficulties, they lead to the conclusion of programmed control. If programmed control can be demonstrated behaviourally, then perhaps programming times for various components of movements can be estimated through the study of reaction times.

The preceeding studies emphasized the lack of feedback criterion as evidence for programmed control. A second, and converging, method of assessing programmed control has concentrated on the structuring and preparation of commands before movement occurs (Klapp, 1978). Reaction time (RT) differences are considered to be evidence of prior structuring of commands, since, they are proposed to be a function of the nature of the response to be made (Kerr, 1977; Klapp, 1978; Rosenbaum, 1978). This approach has enabled researchers to study the preparation of motor responses and the properties of the preparation process.

Response Programming as Assessed by Reaction Times

The study of motor response processes with reaction time measures appears to have a contemporary origin in the "Memory Drum" theory of Henry and Rogers (1960). Henry and Rogers (1960) measured the reaction time of subjects for three movements of different complexities. The movements were (1) a simple finger lift off of a switch, (2) reaching forward and up to grasp a tennis ball, and (3) a complicated series of movements and movement reversals which involved hitting a ball, pushing a button, and hitting a second ball. All movements were triggered with an auditory go signal and reaction time was found to significantly increase with the complexity of movement. These results were interpreted in terms of a memory drum theory of neuromotor reaction. Specifically, a more complicated pattern of movement required a longer latent time because "of more complicated circulation of neural impulses through the coordination centers" (Henry & Rogers, 1960). This interpretation is analagous to that of response programming or open-loop control. By holding perceptual and decision variables constant, changes in reaction time are interpreted as varying degrees of response programming. If the motor programme was simply stored in long-term memory, a greater "circulation of neural impulses" would not be required. The time necessary to select a motor programme should be fairly constant. Therefore, response programming must occur in a memory state other than long-term memory (i.e., short-term memory). Henry (1961) stated that a more complex response necessitated a larger programme. Thus, reaction time is longer since more time is needed to complete the programme. This research provided one the first indications of programmed control which was not based on the lack of feedback criterion.

Other inquiries on the effects of task parameters on reaction time in programmed control remained sparse until the 1970's. Eriksen, Pollack and Montague (1970) spurred further study in this area when they investigated the role of task parameters on the reaction time of verbal responses. Choice reaction time was found to increase with the number of syllables to be pronounced. As the number of syllables increases, the time to read and percieve these was postulated to change appropriately (Eriksen et al., 1970). Klapp, Anderson and Berrian (1973) questioned whether the preceeding explanation was appropriate. In a programming experiment a simple vocal response (yes or no) was made as to whether a visually presented word was an animal or an object. The number of syllables failed to produce any changes in choice reaction time. If the differences in reaction time are a function of the perceptual process, higher response initiation times should have been present. Clearly, an alternative explanation may be needed. The syllables to be pronounced must be programmed between stimulus onset and the start of the articulatory response. Hence, variations in reaction times may only be attributed to the programming of the articulatory response (Green & Shallice, 1976; Klapp et al., 1973). It appears as though reaction time can be used to demonstrate programmed control. If this is the case, are these results congruent with current theoretical positions on movement generation and learning.

The use of reaction time to assess programmed control seems to have a sound theoretical base in Schmidt's (1975) Schema Theory of motor skill acquisition. Schmidt (1975) has postulated two memory systems for movement; the first known as a recall schema, and the second called a recognition schema. The recall schema is responsible for the generation of movement while, the recognition schema is the memory state responsible for the evaluation of incoming feedback produced by movement. The recall schema is the memory state which is relevent to response programming. It is hypothesized that there are generalized motor programmes stored in the recall schema (Schmidt, 1975). The generalized motor programme requires detailed response specifications (e.g., movement duration, movement speed, etc.) that determine how the programme is to be executed. Response specifications are determined according to the initial conditions (e.g., current limb position) and the desired outcome. The response specifications are the parameters requiring programming and may be assessed and possibly estimated by reaction time. Figure 2 from Schmidt (1975) demonstrates the hypothesized movement generation process described above. Reaction time also appears to have sound theoretical implications in related research on mental processes. In fact, many memory models assume that RT reflects memory retrieval time (e.g., Sternberg, 1969). Sternberg (1969) demonstrated that RT increases linearly with the number of items to be searched in memory. Pachella (1974) has provided an excellent review on the varying uses of RT for the reader interested in the possible interpretations of RT research. Since the use of reaction time has a strong theoretical base (e.g., Henry & Rogers, 1960; Schmidt, 1975; Sternberg, 1969) and has been used to validate programmed control, careful consideration of the experimental techniques employed becomes necessary.

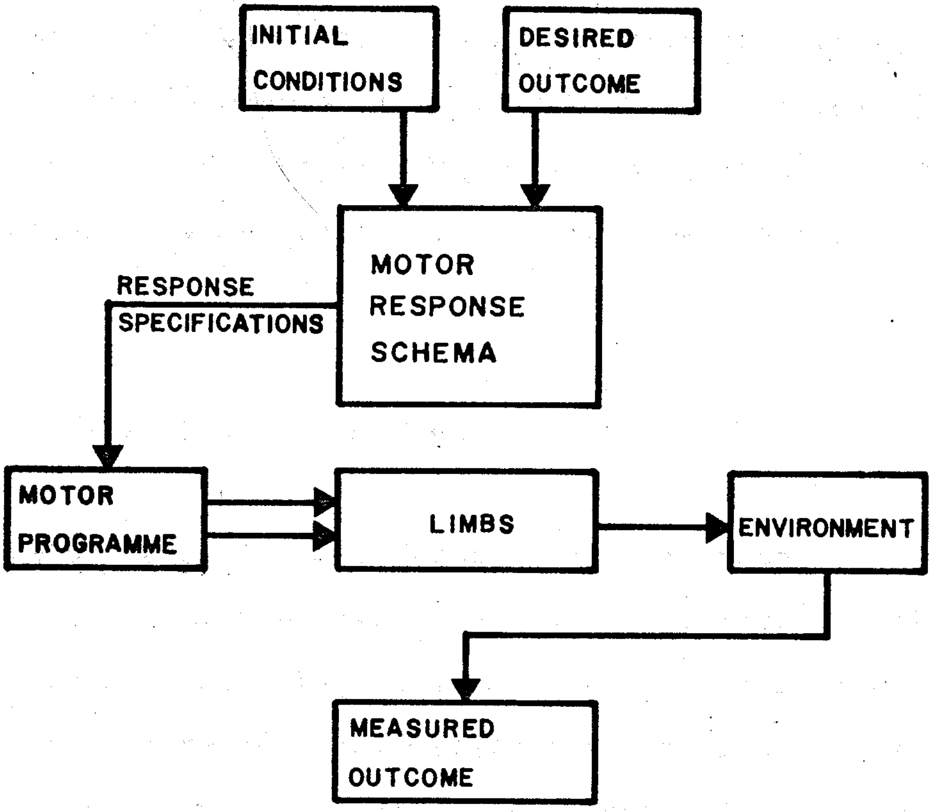

Figure 2. A schematic representation of the movement generation process (adapted from Schmidt, 1975).

A subtle difference exists between the method of Henry and Rogers (1960) and those of the researchers involved with verbal responses. While Henry and Rogers (1960) used simple reaction time, the data presented on articulatory response programming are based on choice reaction times. The aforementioned distinction may seem relatively insignificant but, two schools of thought have emerged on the proper experimental technique for examining programmed control through reaction time. The following sections will present these methods, their shortcomings, and demonstrate why a new approach may be necessary.

Simple Versus Choice Reaction Time

The use of reaction time for the investigation of perceptual and decision processes has been a common practice for many researchers. Since the study of response programming through reaction time is a relatively new concept, a controversy on the proper experimental approach has surfaced[2]. Choice reaction time, rather than simple reaction time, appears to be favoured by the majority of researchers. Klapp (1976, 1978) has been the primary advocate of choice reaction time, while, Henry

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[2] While numerous reaction time techniques have been developed to study human motor behaviour, only a few are discussed. The reader wishing a more extensive review is referred to Pachella (1974) and Taylor (1976).

(e.g., Henry & Rogers, 1960) has suggested that simple reaction time be used. Rosenbaum (1980) seems to have mediated this controversial topic by combining the benefits of both. What are the differences between the two approaches and what are the benefits of each?

The time at which the subject is informed which response is to be produced is what differentiates simple and choice reaction times. A subject performing in a simple reaction time paradigm has been told in advance which response is to be performed before some form of "go" signal is presented. In contrast, the "go" signal also informs the performer which of several responses is required in a choice reaction time paradigm. The decision of which response to make is completed in advance of the start signal in simple reaction time. In addition, the response may be programmed prior to the start signal. Choice reaction time, however, is a function of the detection/recognition, decision, and response processes as all operations are started once the signal to begin execution is presented. Difficulties with both of these techniques may be identified.

In a simple reaction time paradigm, motivated subjects utilize the advance information and programme the response prior to the execution stimulus. Simple reaction time will be shorter than choice reaction time for the same situation (Klapp, 1978). If subjects are not motivated to use the advance information, no differences between simple and choice reaction time will be observed. Also, the differences which may appear due to programming cannot be distinguished. Table 1 from Klapp (1974) illustrates these points. Subjects were required to press a telegraph key for two different durations of time. A short press corresponded to a Morse code "dit" and the longer press was a "dah". The mean simple reaction time of 246 msec. was much faster than the 370 msec for the choice reaction time paradigm. If simple reaction time was employed by itself, the programming effect demonstrated by choice reaction time would be missed. Similarly, subjects lacking motivation need not use the advance information. As a result, programming effects become difficult to interpret.

Klapp (1976, 1978, 1979) has advocated the use of choice reaction time in the study of response programming with simple reaction time serving strictly as a control. Why is simple reaction time necessary? Klapp (1978) has suggested several nonprogramming variables can influence both choice and simple reaction time. Changes in simple reaction time in motivated subjects could reflect:

1) apparatus activation artifacts,
2) differences between responses involving peripheral rather than central control, and
3) nonprogramming central processes (Klapp, 1978).

If differences are observed in both simple and choice reaction

Table 1

Mean RT for Movement Duration*

	Response		
Conditions	dit	dah	Mean
Choice	358	382	370
Simple	246	245	246

* adapted from Klapp (1974)

times, and the effect on choice reaction time is not over and above that of simple reaction time, then the effect cannot be attributed to programming and an alternative explanation is necessary.

Regardless of whether simple reaction time is used as a control or not, choice reaction time still has one inherent problem. Although choice reaction time may be used to show programming effects, it cannot be used to estimate programming times as several researchers have proposed (e.g., Henry & Rogers, 1960; Rosenbaum, 1980). Choice reaction time is a function of detection/recognition time as well as programming time. The latency times for these processes cannot be separated using a choice reaction time paradigm. Nevertheless, research using this technique has identified several task parameters which require preparation. It should be noted that the majority of factors identified by this approach use visually guided movements. In this manner, Fitts' Law (Fitts, 1954) is employed to equalize the difficulty of different responses. Further, responses under visual control must be compatible with the stimulus. If not, latency times are confounded by stimulus-response compatibility. It is now possible to proceed and examine the task parameters which influence response preparation in choice reaction time situations.

Task Factors Affecting Response Preparation

The number of syllables to be pronounced has been observed to increase choice reaction time (Eriksen et al., 1970; Klapp, 1971,1974; Klapp et al., 1973). Two processes could account for the differences in reaction times; a perceptual-recognition process or a response preparation process. The effect observed has been attributed to the response preparation process and not the perception of the stimulus (Johnston, 1975; Klapp et al., 1973). Perception has been discounted as a plausible explanation since the increased reaction time disappears when pronunciation is not demanded.

Movement distance and target width are probably the two task parameters that have drawn the most interest (Brown & Slater-Hammel, 1949; Fitts, 1954; Glencross, 1973; Klapp, 1975). Early work, however, failed to restrict vision and movement time was often the dependent measure (e.g., Fitts, 1954). This amounts to a closed-loop system with the dependent measure overlooking the open-loop aspects of the movement. In the instances where this is not the case, choice reaction time, which reflects response preparation, increased with the physical length of movements (Glencross, 1973; Klapp, 1975; Siegel, 1977). Klapp (1975) has suggested that this result only holds for movements of minimal accuracy. The increased accuracy constraints demand feedback control for the termination of movement. This implies that long accurate movements are not completely programmed before initiation. Similarly, increased accuracy demands (decreased target width) demonstrate choice reaction time effects only in short movements. In longer movements, only the first portion is programmed (Klapp, 1975). Once the feedback from the first portion of the movement has been examined, corrections may be initiated. Therefore, the size of the target does not influence reaction time because movement termination is under peripheral or hybrid control. Results from similar experiments which fail to find changes in reaction time can be accounted for by the preceeding explanation (e.g., Brown & Slater-Hammel, 1949; Kerr, 1978).

The temporal duration of a movement has also been found to require programming (Klapp & Erwin, 1976; Klapp, Wyatt, & Lingo, 1974). Choice reaction time is longer to a key press representative of Morse code "dah" than a "dit" (Klapp et al., 1974). Movement duration, although being a sufficient condition to cause programming, may not be a necessary condition for causing differences in programming time (Klapp & Wyatt, 1976). Responses of longer temporal duration rely on feedback for the completion of the response. Movement duration then, should only require programming if the complete response is to be programmed in advance.

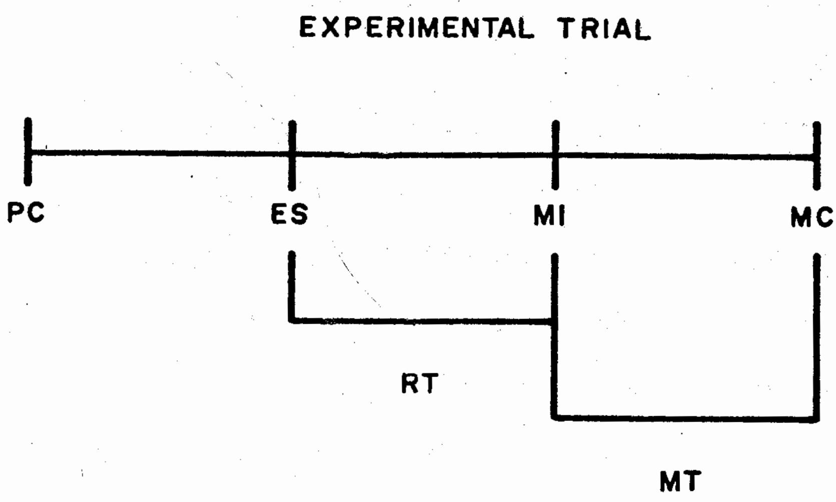
One of the most interesting studies, undertaken by Klapp (1977), employed a variation of the of the dit-dah approach to study muscle specification as a movement parameter requiring preparation. Klapp had subjects perform dit-dah responses with the index finger and thumb. When the required muscle was left unknown, reaction times for the dit and dah responses were equivalent. In the muscle known condition, the differential dit-dah programming effect was observed. From these results, Klapp (1977) concluded that the generation of specific muscle commands must occur in a later stage of processing since programming may occur when the response muscle(s) is not specified.

Tasks requiring multiple responses or the sequencing of responses, only recently have been examined (e.g., Kelso, Southard, & Goodman, 1979; Klapp, 1979). A study by Klapp (1979) revealed that movements of the left and right hands simultaneously were not degraded when they were identical or had harmonically related sequencing periods. Rhythm or response patterning is believed to be a function of programming (Klapp, 1979; Marteniuk, 1976a). Responses without temporal compatibility cannot be generated in parallel. Hence, the resulting interference would be attributed to limitations of response preparation (Klapp, 1979). Data consistent with this expectation have been reported by Klapp and Greim (1979) and Kelso et al. (1979). Equal movements by both hands tended to follow the same temporal pattern (Kelso et al., 1979). As a result, a single temporal base was hypothesized to control the movement of both hands. The temporal sequencing of responses appeared to be an important central process in the structuring of motor commands (Klapp, 1979; Rosenbaum, 1980; Shaffer, 1978).

Several task parameters have been identified as factors requiring programming through a choice reaction time approach. Rosenbaum (1978) has recommended a special case of the choice reaction time technique be used for making inferences about the response preparation process.

The Movement Precuing Technique

A new approach developed by Rosenbaum (1978, 1980) has employed choice reaction time within a precuing or advance information context (Leonard, 1958). The movement precuing technique uses movements that differ in features (e.g., limb, direction, extent) on orthogonal dimensions (e.g., long or short movement). Precues giving advance information about some of the features to be performed are presented in advance of the "go" or execution stimulus (see Figure 3). The "go" signal identifies the remaining features by signalling the required response. The choice reaction time shown in Figure 3 is considered to include (1) the stimulus detection/recognition time; and (2) the motor feature preparation time. Thus, by using different combinations of precuing conditions, the time required for encoding the stimulus and preparing the response may be estimated. Rosenbaum



PC — PRECUE
ES — EXECUTION STIMULUS
MI — MOVEMENT INITIATION
MC — MOVEMENT COMPLETION
RT — REACTION TIME
MT — MOVEMENT TIME

<u>REACTION TIME COMPONENTS</u>

RT = STIMULUS IDENTIFICATION + RESPONSE PREPARATION

Figure 3. A schematic representation of the movement precuing technique (adapted from Rosenbaum, 1978).

(1980) has suggested that the stimulus identification time is minimal and therefore, differential precuing effects are representative of motor feature preparation alone. A true estimate of the stimulus identification and response preparation times, however, has never been completed. In order to control the stimulus encoding time, Rosenbaum (1978, 1980) ensured that no visual scanning of the stimulus array was necessary. This was accomplished through the use of a tachistiscope. Eight coloured dots, each one defining a different response, were presented onto the fovea and hence, eliminated the scanning process. The perceptive reader may realize that the aforementioned procedure forced all responses to be performed without vision. Since all vision is foveal, the same procedures are hypothesized to simultaneously control for stimulus-response (S-R) compatibility. According to Larish (1980), this interpretation is not strictly correct. Coloured dots do not readily signal the stimulus and required response positions. Thus, S-R compatibility is low. Therefore, a colour to position translation must be made. Larish (1980) suggested that the differential programming effects are confounded by this translation and, may even be the cause of these effects. Another problem which may occur as a result of non-visually guided movements pertains to Fitts' Law (Fitts, 1954). Fitts' Law was developed for visually guided movements and has never been tested without vision. Kerr (1978) demonstrated that the preparation of a response does not necessarily have to be completed before movement initiation. Experiments on response programming should also analyze movement times since, systematic changes may be indicative of incomplete response preparation during the reaction time. Therefore, the relationship between movement time (MT) and the index of difficulty as outlined by Fitts (1954) must be examined without vision. Then, a total examination of the response preparation process may continue. This problem, in fact, was addressed by Rosenbaum (1980) in his theoretical review. His discussion leads to consideration of the fact that an understanding of the relationship between movement time and task difficulty is necessary to separate programmed control from closed-loop control. Although some problems may exist in terms of compatibility and Fitts' Law relationships, there are advantages to this approach. Accordingly, some of the questions which may be addressed are:

1) Does it take different amounts of time to prepare each of the movement features (e.g., direction, extent)?
2) Are programming times identical for different values of a feature?
3) Is the preparation of one feature dependent on another feature?
4) Are the features prepared in a strict order?
5) Is the programming of several features performed in

a parallel or serial manner?

Still, stimulus identification time cannot be overlooked since it does contribute to the overall reaction time. A new theoretical approach which will differentiate these two is needed. Even so, the results from the movement precuing technique do compare favorably with that of choice reaction time research.

Research on response preparation via the movement precuing technique has concentrated on the programming of limb, direction, and extent of forthcoming movements. Briefly, the data has coincided well with that of choice reaction time research as all of these features have been found to require preparation (Rosenbaum, 1978, 1980). In addition, preparation times were longest for arm, shorter for direction, and shortest for extent (Rosenbaum, 1978, 1980). With the added control for visual scanning and stimulus-response compatibility, the movement precuing procedure would appear to be the optimal technique.

Since both the choice reaction time and the movement precuing approach have failed to separate the stimulus encoding time from the response preparation time, a task which isolates these times would be preferred. Through careful inspection of the assumptions associated with the movement precuing technique, these two processes can be differentiated. This new approach has combined the ideas of choice reaction time and precuing into a

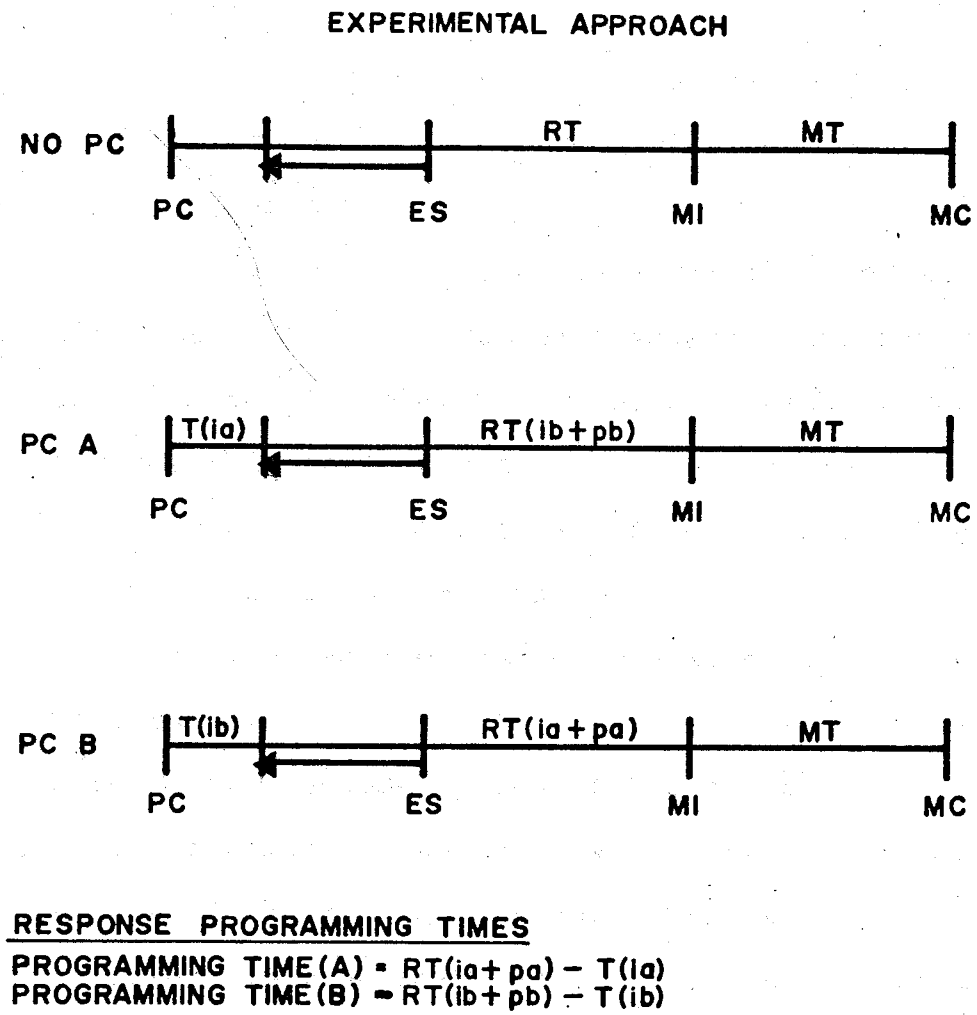


Figure 4. A schematic representation of the new experimental approach for estimating stimulus identification and response preparation times.

single experiment. In so doing, the new technique, while separating stimulus identification time from response preparation time, will provide converging evidence for programmed motor control.

Rosenbaum (1980) has identified five conditions which must be met if movement precuing is to be successful. These conditions may be summarized as:

1) the features must differentiate possible movements;
2) the dimensions on which the movements differ must be psychologically relevant to the control of movement;
3) the possible movements must be discriminable;
4) subjects must not prepare multiple responses based on the precued information and,
5) at least one feature must be prepared during the reaction time.

Figure 4 is a schematic representation of the new experimental approach. In this technique, a movement which differs in terms of two features (as defined by Rosenbaum, 1978) on two orthogonal dimensions is required. The first measure taken is choice reaction time where no precues are given. This measure contains the stimulus identification time and the response preparation time for both features. In the next step, feature A is precued before the execution stimulus identifying the required response. The reaction time following the execution stimulus is a function of the stimulus identification time and the response preparation time for feature B. If the temporal duration between the A-precue and the execution stimulus is decreased, the benefit derived from the precue will eventually dissipate and equal the no precue case. The time between the precue presentation and the point of attenuation represents the stimulus identification process for feature A. Figure 5 is a schematic representation of the hypothesized reaction time curve for varying precue durations. If the same process is repeated when feature B is precued, the stimulus encoding time for feature B can be estimated. Response preparation times for each feature can be calculated by subtracting the identification time from the appropriate preparation plus identification time (see Figure 4).

The perceptive reader may recognize this simple difference as the Subtraction Method first employed by Donders (1869). Donders estimated the duration of mental processes by devising similar tasks that required different amounts of processing. The duration of each successive processing stage was calculated by subtracting the time required for the preceeding stages. Although this technique was popular in the early 1900's, several criticisms created a loss of interest in this method as a device for the inspection of mental processes. Pachella (1974) has written an excellent review of the criticisms and, as such, only a brief discussion is provided here.

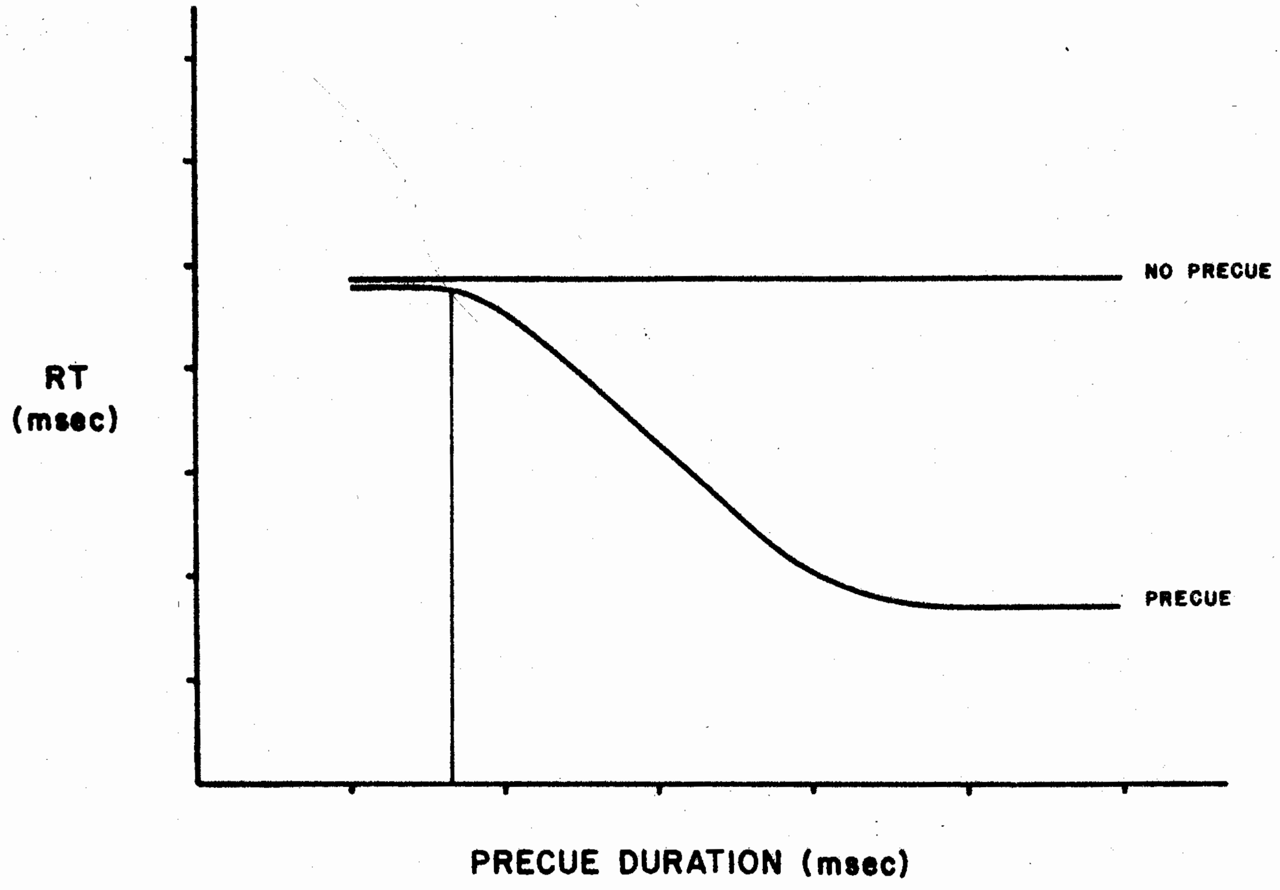


Figure 5. Hypothesized reaction time curve for decreasing precue durations.

First, both the experimental and comparison task need to be similar and comparable. That is, all processes in the experimental task must be identical to the comparison task except for the processing stage of interest. Herein, the problem may be located. There is no guarantee that the additional processing stage will not affect the other stages required to complete the task. Accordingly, the tasks cannot be considered as comparable. Sternberg (1969) upon seeing the benefits of stage analysis modified Donders methodology and introduced the Additive-Factor Method. Instead of changing the number of stages in experimental tasks, Sternberg (1969) attempted to alter the amount of processing or number of operations within a stage. This modification still fails to corrects the major criticism of the Subtraction Method; namely, changing the processing within a stage may change the processing of other stages. Again, tasks are not comparable.

A second criticism of the Subtraction Method is based on the underlying assumptions of information-processing models and research (Pachella, 1974). It is impossible to devise experimental tasks for comparison without knowing what the sequence of mental events are and if they actually exist. Perhaps this criticism was valid when Donders first invented the Subtraction Method but, it would seem to fail now. Presently, there are several information-processing models with empirical evidence supporting the existence of several processing stages.

One of the best examples is the information-processing model developed by Theios (1975).

Theios (1975) has presented five independent processing stages. Input and stimulus identification are the perceptual processes which detect and recognize the stimulus. Response determination is the processing stage where an appropriate response code is selected from the identified stimulus. If the stimulus and response are highly compatible or highly practiced, the time necessary to determine the response is negligible (Theios, 1975). In contrast, when S-R compatibility is low, the time required to determine the response code is increased. In this case, a stimulus-response transformation or translation extends the time necessary to complete response determination (Teichner & Krebs, 1974). As mentioned previously, the S-R compatibility in the precuing approach of Rosenbaum (1980) may have been low. A colour to position translation may have confounded the motor programme construction results (Larish, 1980). Once the response code has been determined, the response programme is selected and executed. The evidence presented by Theios (1975) for each of these processing stages has been used for similar models (e.g. Welford, 1976; Marteniuk, 1976). Thus, the mental events between the appearance of a stimulus and the execution of a response now appear to be documented. Accordingly, how does the processing of information occur? If stimulus identification and response preparation are not serial in nature, the subtraction of one from the other is not valid. Turvey (1973) suggested that the sequence of events between stimulus onset and response output may be partially overlapping. In the information-processing approach, however, various types of analyses are performed on the information that passes through the nervous system. The operations performed at each successive stage are dependent on the output from the previous one (Theios, 1975). The stages then, need to be serial in nature (Theios, 1975; Theios & Walter, 1974). It is still possible though, that the processing within a stage may be parallel. The research by Sternberg (1969) on processing within a stage has proved to be serial. Consequently, this new approach is based on the hypothesis that information is processed serially. This assumption will be indirectly tested by the technique proposed to isolate programming time. The position, albeit default in nature, taken here is that calculations (subtractions) resulting in positive times does not negate the serial or parallel processing notions. On the other hand, negative times would argue for some type of parallel processing.

The new approach for estimation the programming time for various features of a movement is not subject to the criticisms of the Subtraction Method. The number of processing stages does not change for any of the conditions. Similarly, the number of operations within a stage also remains the same. Since the processing stages between the onset of a stimulus and the execution of a response are known, the subtraction of the corresponding times should be considered tenable. Nevertheless, consistent and converging research is necessary in the future.

Chapter 3

GENERAL STATEMENT OF THE PROBLEM

Several research techniques have been developed to study the operation of the motor programme construction process. The three behavioural approaches (i.e., simple reaction time, choice reaction time, and movement precuing) employed in the study of this process, have all failed to separate response preparation time from stimulus identification time. As such, the reaction time measures may be contaminated by non-motor factors (e.g., stimulus-response translation, stimulus identification). Clearly, any conclusion drawn from experimentation on the response preparation process requires further examination. The present investigation attempts to overcome these and other problems through the development of a new theoretical approach. In this manner, the motor programme construction component may be separated from the stimulus identification component contained in reaction time.

As mentioned previously, response programming may not be completed during the reaction time (Kerr, 1978). If this is the case, response programming research cannot be fully explained without an analysis of movement times. Since the precuing approach necessitated that responses be performed without visual feedback, Experiment 1 was designed to determine if Fitts' Law (Fitts, 1954; Fitts & Peterson, 1964) remained unchanged for movements without visual guidance. Fitts' Law states that the movement time associated with a response is related to the distance moved (A) and the target width (W). If the relationships designated by Fitts' Law remain, movement time will be proportional to the distance moved and inversely proportional to the target width. Moreover, changes in movement amplitude and target width, which exactly compensate for each other, should produce no change in movement time. The index of difficulty (ID) for any movement is defined as $\log_2 2A/W$. A linear correlation between movement time and ID should be found if Fitts' Law holds for movements without vision. Thus, a reciprocal tapping task (see Fitts, 1954) will be performed over three different indices of difficulty. Movement times should increase as the level of difficulty increases.

Once the MT and ID relationship is known, the response preparation process may be studied and evaluated. Experiment 2 systematically varied the precue duration (foreperiod) under the precuing paradigm of Rosenbaum (1980). The features direction and extent will be manipulated according to the rationale developed in Figure 4. A response programming analysis of the reaction times is hypothesized to reveal a differential preparation effect between features. The reaction times for the preparation of extent should be less than the reaction times for the programming of direction (Rosenbaum, 1980). If a linear relationship between MT and ID is discerned in Experiment 1, several results should be expected in a movement time analysis. Initially, no difference in MT is expected for responses to targets of equal difficulty regardless of condition. If a difference is noted, this would suggest the response is not totally prepared during the reaction time. In addition, responses to targets of different difficulty are not expected to have identical movement times. This again would signal incomplete response preparation. Finally, if processing is serial as proposed by Theios (1975), manipulation of direction and extent parameters should separate the stimulus identification time from the response preparation time. This distinction will provide an additional understanding of programmed motor control as the relative contribution of each process to the RT will be revealed.

Chapter 4

EXPERIMENT 1

Movement time has been repeatedly defined as the time from the beginning to the end of a response. The factors affecting movement time, however, have not been so easily understood. Most people would assume that movement time is just a function of the distance travelled. Fitts (1954) demonstrated that movement time is also a function of the required terminal accuracy. In general, movement time is denoted by the following equation called Fitts' Law:

$$MT = a + b \log_2 2A/W \text{ or } MT = a \bullet b(ID)$$

where, a and b are constants, A is the movement amplitude or distance, W is the target width, and ID is the index of difficulty. From this mathematical relationship, the average movement time for any given response should remain constant as long as the index of difficulty remains constant. Research has confirmed that this relationship holds for both discrete and repetitive self-paced tasks (e.g., Fitts, 1954; Fitts & Peterson, 1964; Keele & Posner, 1968). Since Fitts' Law describes changes in movement time very well, how might it be explained?

The most frequent explanation is in terms of feedback processing. When a person is moving toward a target, deviations of the hand can be detected and corrected. The farther the distance or the narrower the target, the more corrections needed (Keele & Posner, 1968). Consequently, increased movement times are a function of the number of corrections that are required. On these grounds, the processing of visual feedback appears to be a prime determiner of movement time.

On the other hand, what if visual feedback is unavailable for processing. Does Fitts' Law remain unchanged when corrections cannot be made through vision? If so, then what processes determine the function? These questions developed as a result of the procedures employed in the movement precuing technique of Rosenbaum (1978, 1980). Since movement time may signal incomplete response preparation in the reaction time (Kerr, 1978; Rosenbaum, 1980), the expected relationship to ID must be known for an overall interpretation of response programming. The major objective of the present experiment was to determine if Fitts' Law explained systematic changes in movement time when vision is removed. This knowledge will allow the theoretical implications of movement time to be fully understood in Experiment 2. If the same relationship holds for non-visually guided movements, a significant linear correlation between MT and ID is anticipated.

Method

Subjects. Nine Simon Fraser University students (8=male; 1=female), ranging in age from 21 to 25, volunteered to participate in the experiment. All subjects were right-handed and task naive.

Apparatus. The apparatus was composed of a response panel, a counter/timer, and a five volt power supply. The response panel (25 x 12.5 cm) consisted of a plastic base with an aluminum plate mounted on top. Three pairs of targets, previously punched from the plate, were also mounted on the plastic base (see Figure 6). Movement amplitudes and target widths are presented in Figure 6. One electronic switch for each target was mounted on the underside of the plastic base. In addition, a seventh electronic switch was attached to the base aluminum plate. A five volt electrical current was passed through the subject's body by means of a surface electrode. Whenever the subject's index finger contacted a target or the aluminum base, a "hit" was recorded on the counter. The total number of hits as well as the number of errors was recorded for any one trial. The subjects view of the response panel for all trials was removed by means of a blindfold.

Procedure. Upon entering the testing area, each subject was seated at the midline of the movement range. Before testing began, subjects were given a brief explanation of the reciprocal

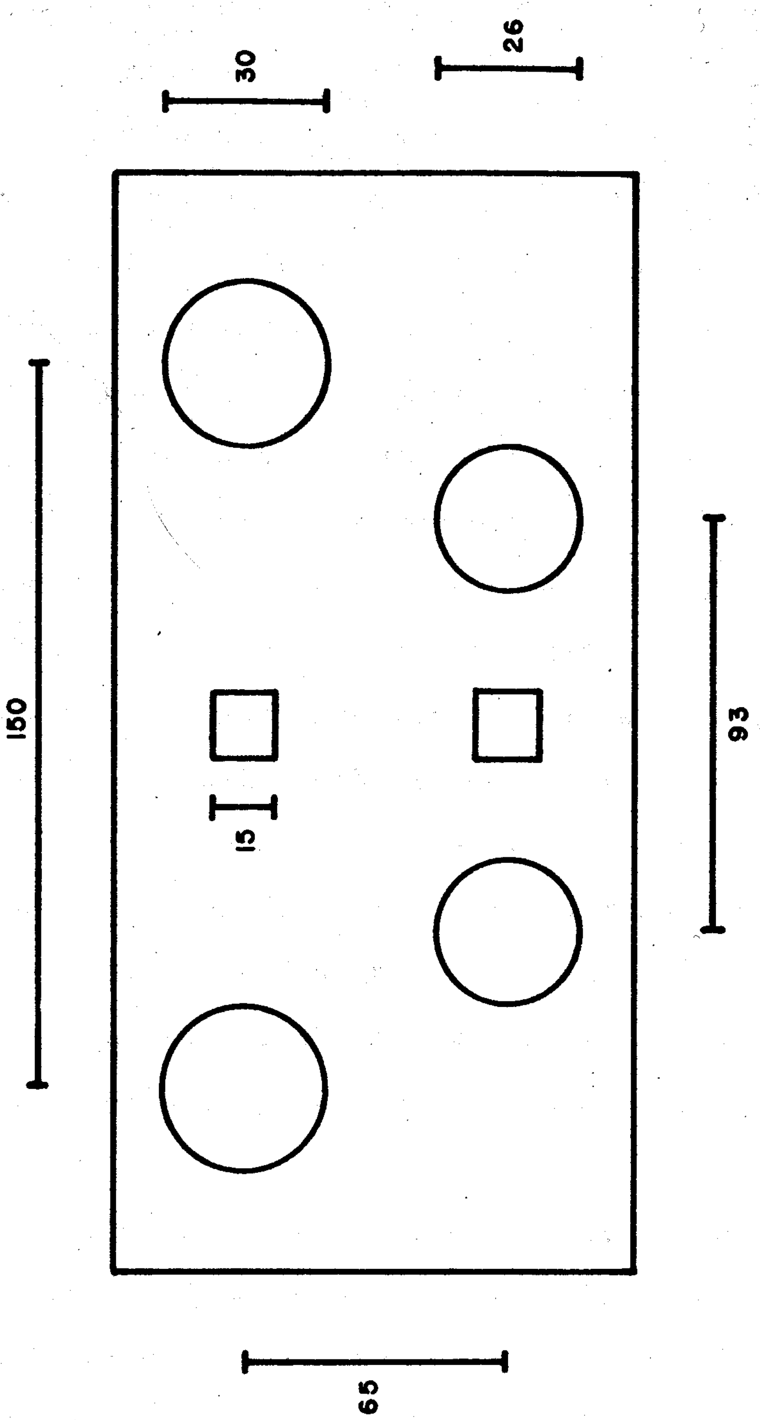


Figure 6. A pictorial representation of the response panel in Experiment 1 (all measurements are in mm).

tapping task (see Fitts, 1954). Subjects were instructed to move as fast as possible while alternately tapping the two targets. All subjects were also informed to move at a speed where they would not produce errors. On any one trial, the total number of taps between targets was recorded along with the total number of misses. If the error rate for any one trial was greater than 10%, the trial was repeated. A ten minute practice session preceeded the testing of each ID condition. In the first half of all practice sessions, tapping was performed with the aid of vision. After the subject had learned the basic experimental requirements, vision was removed for the remainder of the practice session. While practicing without visual feedback, the experimenter provided verbal feedback to help maintain movement accuracy. A series of fifteen trials, each trial being 30 sec in duration, were administered following all practice sessions. Trials one through five were designated as learning trials in which subjects would discover their maximum work rate. Finally, the ID factor was counterbalanced across subjects to prevent an order effect.

Design and analyses. The experimental design was a within subjects design. All subjects completed 15 trials in three different ID conditions (2.9, 3.11, and 3.32 bits). A regression equation was developed to determine if the relationship between movement time and ID was linear. The correlation coefficient was tested for statistical significance and, the error of prediction was calculated. The narrow range of ID was selected because it closely approximated the difficulty levels employed by Rosenbaum (1980). This would provide an optimal understanding of the MT-ID relationship for the programming analysis in Experiment 2.

Results and Discussion

The mean movement times for the learning trials and test trials are presented in Table 2. The associated error rates may be found in Appendix A-1. The highest error rate (5.4%) for the test trials occured in largest ID condition. Thus accuracy was not traded-off for speed. The relationship between movement time and ID was determined through a Pearson product moment correlation. A statistically significant correlation ($r=.724$) was determined, $\underline{t}(25)=5.24$, $p<.05$. Paralleling the analyses of Fitts and Peterson (1964), a regression equation for movement time was developed where, $MT=367.2ID-696$ msec. The linear relationship between movement time and difficulty may be observed in Figure 7. Movement time increased with the level of difficulty. Finally, the standard error of estimate for the regression equation was found to be ±61.2 msec.

It is obvious from the results that the hypothesized linear realtionship between MT and ID was realized. The correlation of .724, while not being extremely large, empirically justified Fitts' Law for non-visually guided movements. Movement time for

Table 2

Mean MT and Standard Deviations for Experiment 1

		ID		
		2.9	3.11	3.32
Learning Trials	$\overline{X}$	367	445	477
	S	41.7	67.4	62.9
Test Trials	$\overline{X}$	364	457	518
	S	37.1	65.4	79.4

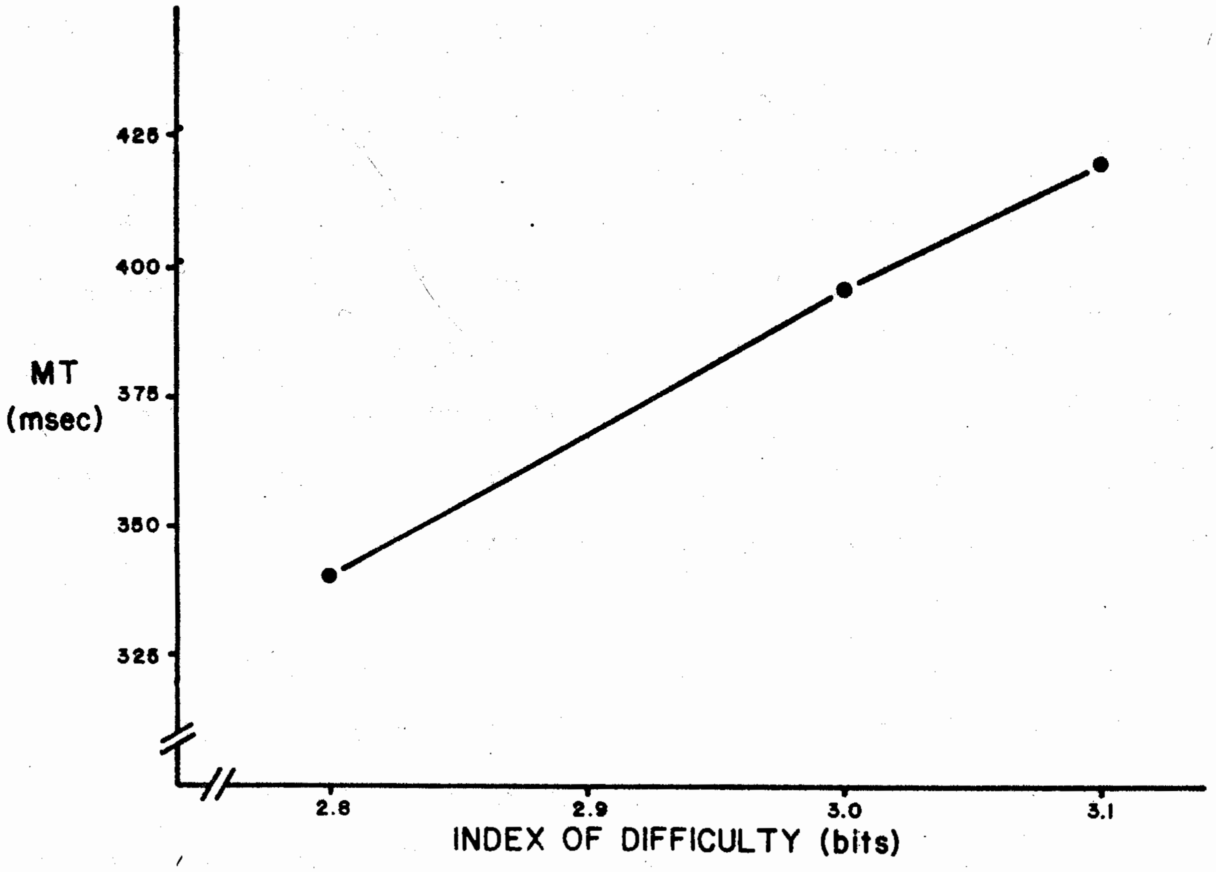


Figure 7. Mean movement times (msec) for the three indices of difficulty.

response without vision is a function of the distance to be travelled and the terminal accuracy required. In spite of this finding, several key components of the results must be questioned. First, the mean movement times appear inflated. If vision had been allowed, the three tapping tasks would have been judged as fairly easy. Fitts (1954) and Fitts and Peterson (1964) reported a correlation of approximately .98 for movements of similar difficulty. The mean movement time for an ID of 3 was approximately 280 msec. Since the human motor system normally relies heavily on visual information, the lack of visual guidance may have produced a situation which was not optimal for extremely rapid movements. This effect may have been more pronounced because of the high accuracy constraints required. This may also account for both the high variability in the movement time distributions and the high error of estimate for the regression equation. Nevertheless, a significant linear relationship between movement time and ID was found. A key question arises from this interpretation. How can this relationship be explained when vision is removed? The number of visually based corrections approach is no longer tenable. A subject cannot make visual corrections for deviations from the intended movement path when the intended path cannot be seen. Proprioception based corrections, however, may explain changes in movement time. The expected sensory consequences of the response serve as the intended goal and deviations from the intended goal are corrected (Schmidt, 1975). The impulse-timing model proposed by Schmidt, Zelaznik, Hawkins, Frank and Quinn (1979) also provides an alternative explanation.

The model given by Schmidt et al. (1979) stated that the terminal accuracy of rapid or ballistic movements is related to the variability of the initial movement impulse. According to Sherwood and Schmidt (1980), the initial impulse can be viewed as the aggregate of the accelerative forces acting in the direction of the response endpoint. Logically, any parameter which increases the impulse variability would also increase the variability of the response. Schmidt et al. (1979) quantified this logic by proposing the following relationship;

$$We \alpha A/MT$$

where, We is the standard deviation of responses around a fixed target, A is the movement distance, and MT is the movement time. Therefore, if a subject attempts to move a given distance (A), to a target of fixed width at too great a rate, the variability of the responses (We) will be high. By decreasing the velocity of the response, the ratio of A/MT is reduced and the response becomes more accurate. A large initial impulse means the subject will cover the movement distance in a short period of time. A smaller initial impulse increases movement time and decreases the response variability (errors). In this manner, the relationship between MT, target width, and movement distance can be explained in the absence of vision.

Now that the functional relationship between MT and ID has been defined, the expected movement time differences in a response programming approach may be outlined. Before moving on to the second experiment though, several modifications to the present experiment might have produced stronger results. A larger range and greater number of ID's would have provided more data and possibly a stronger linear relationship. Similarly, a larger range would have given more information regarding the upper and lower limits that subscribe to this relationship. The present experiment also confined its scope to that of a repetetive self-paced task. Fitts' Law has also been shown to remain constant for discrete motor responses (Fitts & Peterson, 1964). If discrete motor responses had been included, the generalizability of the findings would be greatly enhanced. Future research then, should take these considerations and place them in an appropriate experimental setting.

Chapter 5

EXPERIMENT 2

In order to gain an understanding of the motor programme construction process, Rosenbaum (1978, 1980) refined the partial advance information paradigm of Leonard (1958). The movement precuing technique presented by Rosenbaum (1980), however, fails to provide an adequate description of this process. The reaction time measures, which are hypothesized to reflect the response preparation process, are contaminated by non-motor factors (Goodman & Kelso, in press; Larish, 1980). Specifically, the reaction time in the Rosenbaum (1980) research is a function of a S-R translation and stimulus identification. The second experiment was developed to overcome the difficulties encountered in the movement precuing technique. The underlying theoretical assumptions associated with the precuing approach (see Figure 5) were isolated and manipulated. In this manner, it was hypothesized that the role of the stimulus encoding process in response programming could be ascertained. Moreover, the present experiment was designed as an extension and replication of the Rosenbaum (1980) paper.

The initial experiment examined a question which arose from the procedures employed in the movement precuing technique; namely, whether or not the relationship described by Fitts' Law remained invariant in the absence of vision. Taken together, the findings from the first experiment indicated that MT increases as the index of difficulty becomes larger.

Movement time analysis is proposed to be an integral part of the response programming framework (Kerr, 1978; Rosenbaum, 1980). Within this context, movement times have an important role in distinguishing if motor programming was completed during the response latency period. Now that the relationship between MT and ID has been delineated, a proper analysis of response programming in the precuing approach may be completed. With respect to movement time, no differences are expected between conditions for responses to targets of equal difficulty. If a difference is found, it is possible that response preparation is not finished in the reaction time. Similarly, if movement times differences fail to appear in responses to targets of varying difficulty, subjects may not be preparing the entire response in the reaction time. In these situations, the movement is initiated and completion depends on proprioceptive feedback.

If the results from Rosenbaum (1980) are accepted as being valid, then similar effects would be anticipated in the programming (reaction time) analyses. A differential programming effect between direction and extent should be noted. The response perparation time for extent is hypothesized to be less than that of direction. Similar investigations by Larish (1980) and Goodman and Kelso (in press) failed to replicate the Rosenbaum (1980) results when S-R compatibility is high. In light of these results, the present study will also include a replication of these important findings.

Method

Subjects. Eight Simon Fraser University students (6 male; 2 female), ranging in age from 22 to 34, volunteered to participate in the experiment. Again, all subjects were right handed and task naive.

Apparatus. The experimental apparatus was rather complex, and as such, a lengthy description is necessary. First of all, an Apple II microcomputer was the heart of the apparatus. The computer collected the data and controlled the entire experiment. A response panel (25 x 12.5 cm), similar to that of Experiment 1, was situated 20 cm in front of the subject and was interfaced to the computer through a parallel interface card. The home key, a 1.5 cm square, was the position from which all trials started. Four other targets completed the response panel (2 forward, 2 behind). The targets were 7.6 cm and 3.2 cm from the home key, and had diameters of 3.2 cm and 2.6 cm respectively (see Figure 8). Each target was connected to an electronic switch mounted on the underside of the response panel. In addition, the surrounding aluminum plate was also connected to switch. All targets were touch sensitive when a 5 volt current was passed through the subject's body. The

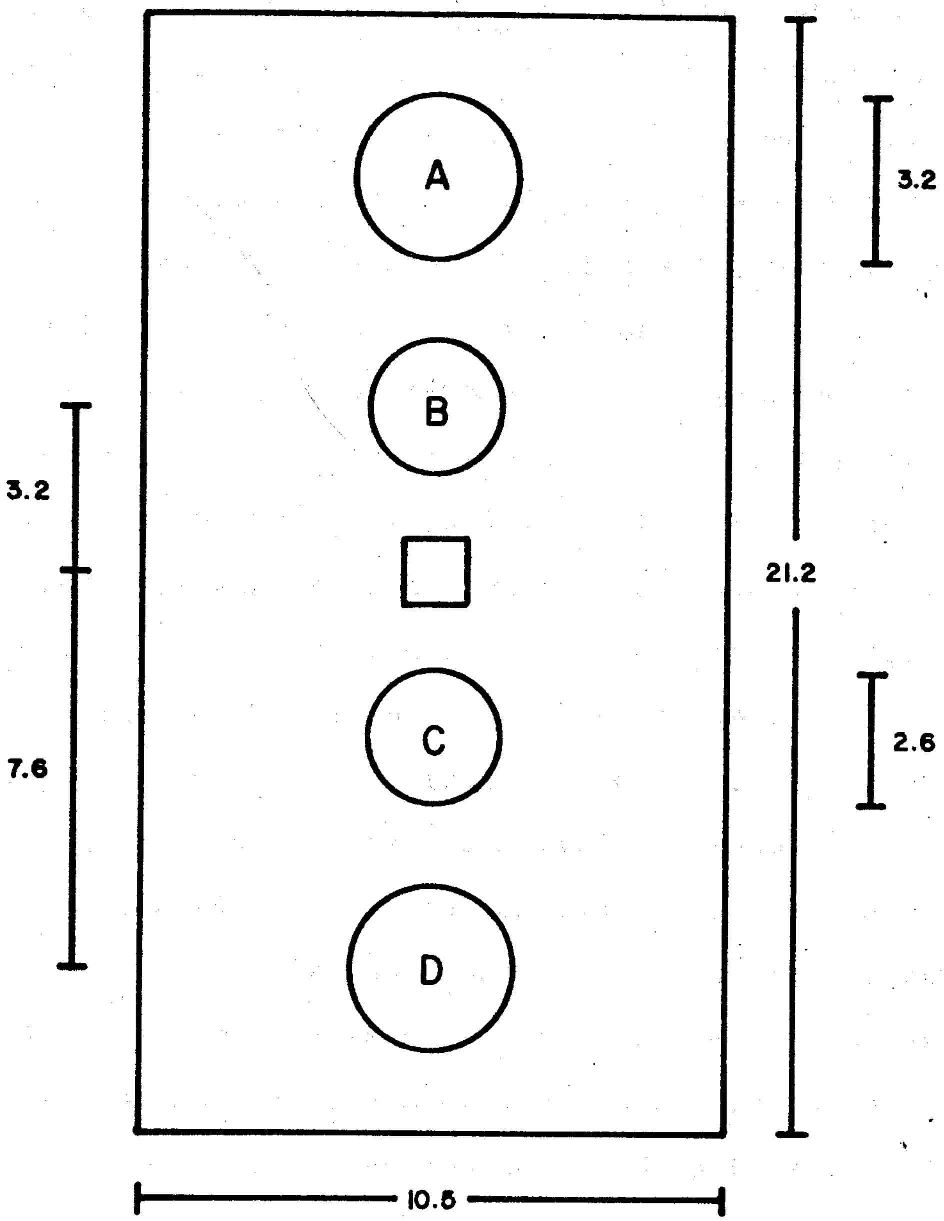


Figure 8. A schematic representation of the response panel used in Experiment 2 (all measurements are in cm).

electronic switches have a distinct advantage over the normal switches commonly used in the laboratory setting. The switching time of the electronic circuitry was less than 1 msec. Mechanical switches may take as long as 40 msec. Futhermore, this time varies from trial to trial. Since the Apple II microcomputer has graphic capabilities, a television monitor was used for the visual display. The visual display was situated at eye level approximately 2 meters away from the subject. The display, which was identical to that of the response panel, measured 18 cm by 9 cm. Five hollow circles, drawn on the monitor by the computer, were positioned to directly correspond to the response panel. The required response was signalled when one of the five circles filled in. At the start of a trial, one of five possible letters (F,B,N,D,X) would appear to the immediate left of the visual display (see Figure 9). The letters were 6 cm high by 3.5 cm wide and served as precues for direction (F=forward; B=backward) or extent (N=near; D=distant). If X was presented, the subject was given no advance information and any one of the four movements was possible. The subject's view of the response panel was obstructed by the use of a modified blindfold. After the completion of a trial, subjects were presented with two other letters in the lower left hand corner of the television monitor (either A,B,C,D, or X). If the two letters matched, the preceeding response was correct. Reaction times and movement times were measured by a real time clock (accurate to .001 sec) contained in the computer.

Procedure. Prior to the start of the experiment, the nature of the task was described to each subject. Before practice of the experimental procedures began, subjects were given a half hour warm-up session. In this session, the subject practiced moving to each target with vision until he/she felt that they had mastered the four possible responses. At this point, vision of the response panel was occluded for the rest of the experiment. Subjects then practiced making the responses without vision for the remainder of the half hour. The concept of advance information (precues) was introduced after the initial warm-up period terminated and, 240 practice trials were given to familiarize the subject with the experimental paradigm. A precue duration of 1200 msec was chosen for the familiarization period. This allowed the subject ample time to make use of the advance information given.

The subject initiated the sequence of events on any one trial by touching the home key. The precue was then presented to the left of the visual display for 1200 msec. For example, if "F" was displayed, the subject knew in advance that the required response would be forward. In this case, only extent required programming during the RT. The subject was instructed to use this information to help prepare for the upcoming response. Once the precue had been presented for 1200 msec, a movement light (filled circle) signalled the desired response. The task was to

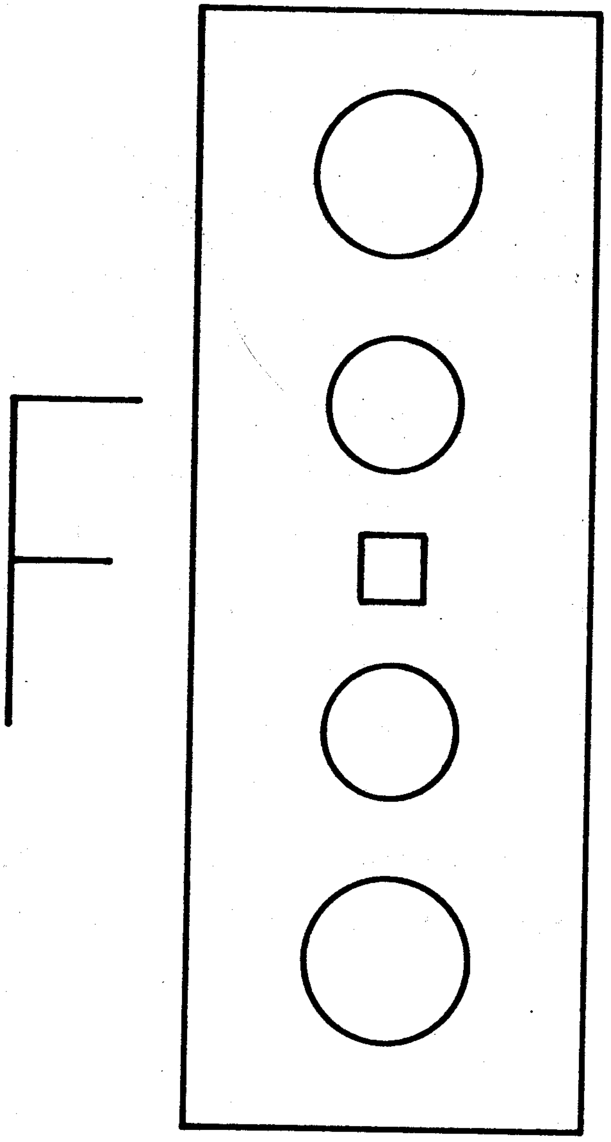


Figure 9. A pictorial representation of the visual display used in Experiment 2.

remove the index finger from the home key and move as quickly and accurately as possible to the corresponding target. Subjects were also instructed to refrain from guessing which of the possible responses would be required. Upon the completion of the 240 practice trials, the data was plotted by the computer and a visual inspection was performed. If the reaction times had not stabilized, or if the error rate was greater than 10%, an additional 120 practice trials were given.

When the warm-up session and practice trials were finished, the remaining experimental trials were started. The twelve possible precue-target combinations were tested twenty times in each of nine different precue durations (i.e., 200, 250, 300, 350, 600, 650, 700, 750, and 800 msec). These times were chosen from pilot data (see Appendix B-1) because they appeared to adequately cover the reaction time-precue duration curve (Figure 4). A random presentation order was determined by the computer for each subject. Since the subject controlled the presentation rate of trials, rest periods could be taken when desired. Each subject completed three testing sessions approximately two hours in duration.

Two movement features (parameters) were manipulated in this experiment. If direction was precued by an "F" or "B", extent had to be programmed during the reaction time. When extent was precured with an "N" or "D", direction has to be prepared during the reaction time. If an "X" was presented, both direction and extent were programmed during reaction time.

The three dependent measures recorded on any one trial were:

1) Reaction Time
2) Movement Time
3) An Error (defined as the touching of an incorrect response target).

Several other types of errors were possible in the present experimental paradigm. A maximum RT of 500 msec and a minimum of 100 msec were set for all subjects. A RT of less than 100 msec meant the subject was anticipating the onset of the execution stimulus. The upper limit was chosen because the RT's for pilot subjects were all less than 500 msec. If the RT exceeded the maximum, or was less than the minimum, the trial was randomly repeated later in the experiment. Similarly, 180 and 10 msec were the maximum/minimum movement times allowed. The maximum MT of 180 msec was selected to prevent responses which were started in the wrong direction and then corrected from being counted as a completed trial. If MT was less than 10 msec, subjects were sliding their finger to the desired target. Only misses and responses to incorrect targets were recorded as errors. The reaction and movement times for errors were removed from the data analyses. Finally, each subject was constantly reminded to maintain an overall error rate of less than 10%.

Design and analyses. A within subjects design was employed in the present experiment. The data were analyzed so that: 1) questions regarding response programming could be addressed, and 2) the time for stimulus identification and response preparation was estimated. A number of questions require inspection in the response programming analyses. When the subject has enough time to make use of the precued information, two hypotheses need to be tested. Initially, is there a difference in reaction time for the different features (direction vs. extent)? Secondly, are there differences between the levels of each feature (forward vs. backward and long vs. short)? An overall test is also required in order to determine if there is a precue by precue duration interaction. For example, it is conceivable that a longer precue duration is necessary for the precue "B" than "F". An analysis of variance, for each hypothesis of interest, was used to test for statistically significant differences. The analysis of variance tables for all dependent measures may be found in the Appendices. Every hypothesis of interest was tested with $\alpha = .05$, and was considered to be statistically significant when the probability of significace was below this value. With respect to the stimulus identification analysis, RT for the precued conditions and no precue conditions was plotted for all precue durations. The standard error of the mean ($S\bar{x}$) for the no precue condition was also calculated and plotted. Assuming there was a linear relationship between the precued feature reaction times at precue durations of 200 and 250 msec, the precue duration at which the feature reaction time deviates two standard errors of the mean is called the stimulus identification time (Figure 12 and 13).

Results and Discussion

Response programming analysis. Through an overall analysis of the RT data for both precued features, precue durations of 700, 750, and 800 msec were selected as the durations where subjects had sufficient time to preprogram the advance information given. The precue duration of 1200 msec was not chosen because it was used for practice trials. Since subjects were not completely familiarized with the task, inflated reaction times occured for the first few trials. The same logic also applies for error rates. Over the course of the experiment, all subjects maintained an error rate less than the 10% criterion. As expected, most errors occured for a precue duration of 1200 msec. The error rates are presented in Table 3. Careful observation of the tabled values also reveals that more errors were made for responses to target D. The differential error rate percentage leads to the assumption of a speed-accuracy trade-off for all responses to target D. Reaction times, however, prove this to be a false assumption. In most

Table 3

Error Rates (%) for Experiment 2

	Precue Duration									
Precue-Target	200	250	300	350	600	650	700	750	800	1200
F - A	3.1	3.1	2.5	3.1	1.2	3.7	5.6	3.1	1.2	3.7
F - B	2.5	1.2	2.5	0.6	1.2	0.6	0.6	0.6	2.5	4.3
B - C	4.3	1.2	1.2	2.5	4.3	7.5	3.1	5.0	1.8	4.3
B - D	7.5	7.5	9.3	7.5	2.5	7.5	3.7	6.2	3.1	8.1
N - B	2.5	1.2	2.5	0.6	1.2	4.3	0.6	2.5	1.8	3.7
N - C	1.8	0.6	0.6	0.6	5.6	1.8	1.8	3.1	1.8	8.1
D - A	4.3	4.3	5.6	3.7	4.3	5.6	3.7	3.7	6.2	14.3
D - D	4.3	4.3	4.3	3.7	5.6	1.8	6.2	4.3	6.2	11.8
X - A	3.1	2.5	5.0	3.1	3.7	4.3	5.0	3.7	2.5	11.8
X - B	2.5	1.8	1.2	1.2	1.8	0.6	1.2	1.2	2.5	3.7
X - C	3.1	1.2	1.2	3.1	5.0	0.6	3.7	3.1	1.8	19.3
X - D	1.2	1.2	8.1	6.8	5.0	6.2	3.1	8.1	6.8	11.8

cases, movements to target D had the largest reaction times. The other error rates do not appear to be large enough to create interpretation problems with the data.

A. Movement time analyses - The four movement time analysis of variance tables may be found in Appendices B-2 through B-5. The overall analyses will be discussed first. When distance was the precued feature, the main effects of presentation letter and direction were significant, *F*(1,7)=516.69 and *F*(17)=42.21. Movement times were shorter when "N" (66 msec) rather than "D" (89 msec) was precued. Forward movements (72 msec) were faster than backward movements (82 msec). The direction by precue duration interaction was also significant, *F*(9,63)=5.89. Further analysis revealed that movement times remained constant across duration for backward movements, while, movement times increased across duration in forward responses. If advance information was given on direction, the main effects of presentation letter, extent, and foreperiod were statistically significant, *F*(1,7)=39.57, *F*(1,7)=471.61, and *F*(9,63)=3.77. Again, forward responses were significantly faster than backward responses (67 msec vs 83 msec). Movement times to the near targets (60 msec) were shorter than those to the distant targets (90 msec). Post hoc analysis of precue duration, using Tukey's HSD test, revealed the simple pairwise differences displayed in Table 4. A statistically significant presentation letter by precue duration interaction was noted, *F*(9,63)=3.07. Subsequent analysis showed

Table 4

Simple Pairwise Differences for Precue Duration (MT)

				Precue Duration						
200	250	300	350	600	650	700	750	800	1200	
	1.7	3.3	1.4	5.4	5.2	3.1	3.9	2.4	2.4	200
		1.6	0.3	7.1*	6.9*	4.8	5.6	4.1	4.1	250
			1.8	8.7*	8.5*	6.4	7.2	5.7	5.7	300
				6.8	6.6	4.5	5.3	3.8	3.8	350
					0.2	2.3	1.5	3.0	3.0	600
						2.1	1.3	2.8	2.8	650
							0.8	0.7	0.7	700
								1.5	1.5	750
									0.0	800
										1200

-Direction Precued (Prepare Extent)

* denotes $p<.05$

that movement times for forward movements remained constant across durations, where, movement time decreased for backward movements across all durations.

Obviously, subjects require time to use the advance information which they are given. Therefore, movement time was analyzed for just the 700, 750, and 800 msec precue durations. Since subjects had sufficient time to prepare the information presented, the three durations are treated as replicates. When distance was the advance information available, significant main effects of presentation letter and direction were found, *F*(1,7)=95.47 and *F*(1,7)=7.61. Movement times were shortest when "N" was the precued letter (67 msec vs 92 msec). Forward responses were faster than backward responses (76 msec vs 83 msec). If direction was the precued feature, significant main effects were found for presentation letter and extent, *F*(1,7)=38.97 and *F*(1,7)=389.07. Forward and near movement times were shorter than backward and distant movement times respectively.

In general, the results from the movement time analyses did not differ from what was predicted by the first experiment. Movement times to near targets were shorter than those to distant targets. Forward movements were also slightly faster than backward movements. The findings do not appear to indicate that response preparation was incomplete during the RT.

B. Reaction time analyses - Of special interest in the reaction

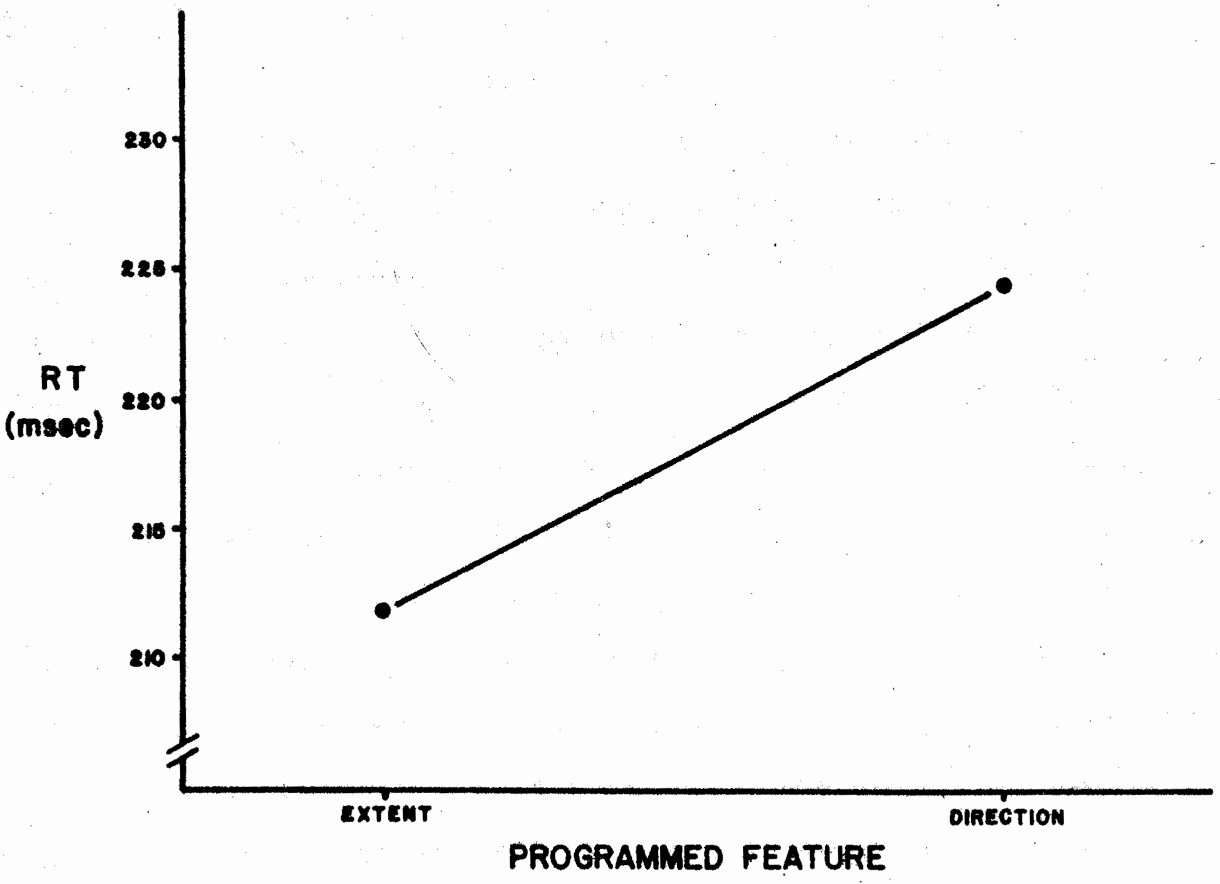


Figure 10. Mean response preparation times for the features direction and extent.

time analyses, was a possible feature preparation difference. More specifically, is there a differential programming effect between direction and extent. This differential effect is of interest only when subjects have sufficient time for preprogramming the advance information. Therefore, the 700, 750, and 800 msec precue durations were used. The analysis of variance table may be found in Appendix B-6. A significant main effect for the programmed feature was found, $\underline{F}(1,7)=11.58$ (Figure 10). When direction is precued, extent must be programmed during the reaction time and vice-versa. The RT for the preparation of direction (224 msec) was significantly longer than the RT for the programming of extent (212 msec).

The next question of relevence deals with the different values (levels) of each feature. Are there differences between the two values of a feature? For example, does it take longer to prepare to move backwards than forwards? Once more, the precue durations of 700, 750, and 800 msec are employed as replicates. When distance is the precued feature, no significant main effects or interactions are found (Appendix B-7). On the other hand, when direction is known in advance, a presentation letter by extent interaction was significant, $\underline{F}(1,7)=9.13$. Further analysis displayed the cause to be a decrease in reaction time for the backward distant movement (Figure 11). In an overall analysis, with distance the precued feature, the main effects of presentation letter and precue duration were significant, F(1,7)=6.19 and F(9,63)=6.58. Reaction times were significantly shorter when "N" was precued (233 msec vs 241 msec). The simple pairwise differences in precue duration can be seen in Table 5. A presentation letter by precue duration was also found to be statistically significant, F(9,63)=2.41. If direction was the feature known in advance, a significant main effect of precue duration was observed, F(9,63)=5.7. A presentation letter by extent and an extent by precue duration interaction were discovered, F(1,7)=8.98 and F(9,63)=3.56. Simple pairwise differences for precue duration are shown in Table 6. Subsequent analysis of the presentation letter by extent interaction revealed the cause to be a decrease in RT for backward distant movements.

With respect to the hypotheses of interest, the significant differential programming effect for features was identical to that reported by Rosenbaum (1980). Reaction times when extent had to be specified were shorter than RT's when direction had to be specified in the latent period. Inspection of the subject means revealed that this trend was true for all subjects but one. This suggested that the effect was fairly reliable.

The preceeding conclusion was based on differences in mean reaction times for different features. The results failed to find differences between individual values within each feature. This result was also identical to that of Rosenbaum (1980).

Table 5

Simple Pairwise Differences for Precue Duration (RT)

				Precue Duration						
200	250	300	350	600	650	700	750	800	1200	
	25.9*	34.1*	43.9*	28.8*	37.4*	47.7*	50.3*	51.7*	37.2*	200
		8.2	18.0	2.9	11.5	18.8	24.4	25.8	11.3	250
			9.8	5.3	3.3	10.6	16.2	17.6	3.1	300
				15.1	6.5	0.8	6.4	7.8	6.7	350
					8.6	15.9	21.5	22.9	8.4	600
						7.3	12.9	14.3	0.2	650
							5.6	7.0	7.5	700
								1.4	13.3	750
									14.5	800
										1200

-Direction Precued (Prepare Extent)

* denotes $p<.05$

Table 6

Simple Pairwise Differences for Precue Duration (RT)

Precue Duration										
200	250	300	350	600	650	700	750	800	1200	
	24.9	40.4*	46.8*	33.1*	41.0*	49.5*	54.0*	54.3*	41.7*	200
		15.5	21.9	8.2	16.1	24.6	29.1	29.4	16.8	250
			6.4	7.3	0.6	9.1	13.6	13.9	1.3	300
				13.7	5.8	2.7	7.2	7.5	5.1	350
					7.9	16.4	20.9	21.2	8.6	600
						8.5	13.0	13.3	0.7	650
							4.5	4.8	7.8	700
								0.3	12.3	750
									12.6	800
										1200

-Extent Precued (Prepare Direction)

* denotes p<.05

Table 7

Mean RT in the No Precue (Prepare Dir/Ext) Condition

Precue Duration

Precue - Target	200	250	300	350	600	650	700	750	800	1200
X - A	272.7	271.3	266.5	270.1	286.3	277.9	269.9	278.1	268.8	290.7
X - B	268.9	259.5	252.9	250.4	280.2	274.9	272.4	268.1	271.6	267.7
X - C	270.2	263.8	256.4	254.7	278.1	280.6	273.4	269.7	264.3	269.3
X - D	276.5	270.1	263.4	260.0	281.4	277.2	265.4	275.9	263.9	269.1
$\bar{X}$	272.0	266.2	259.8	258.8	281.5	277.7	270.1	272.9	267.2	274.2

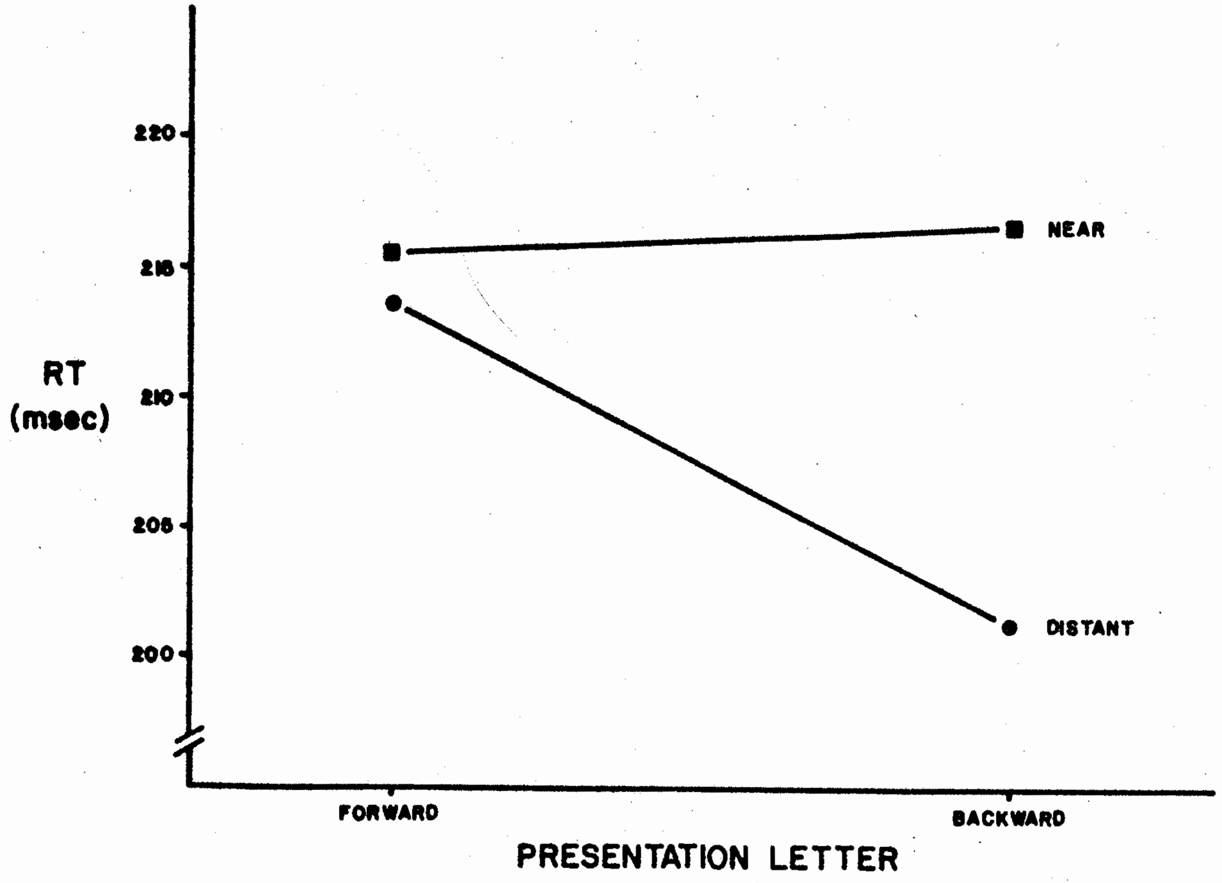


Figure 11. Mean reaction time for the presentation letter by extent interaction.

Table 8

Mean Response Preparation Times

Prepare Direction

	200	250	300	350	600	650	700	750	800	1200
N										
F	256	242	228	224	238	228	225	222	214	232
B	267	248	243	226	242	233	227	212	217	233
D										
F	286	250	243	232	248	239	237	223	226	241
B	281	247	240	232	247	241	223	231	226	235
Prepare Extent										
F										
D	273	245	230	225	236	226	214	213	214	231
N	257	230	219	217	229	221	218	215	212	223
B										
D	267	246	220	214	234	217	205	200	203	213
N	261	238	227	215	228	231	223	215	213	224

Table 9

Mean RT for the Preparation of Direction and Extent

PC Direction (Prepare Extent)

Dist	Near	$\bar{X}$
214.4	209.7	212.1

PC Extent (Prepare Direction)

For.	Back	$\bar{X}$
219.7	227.6	223.7

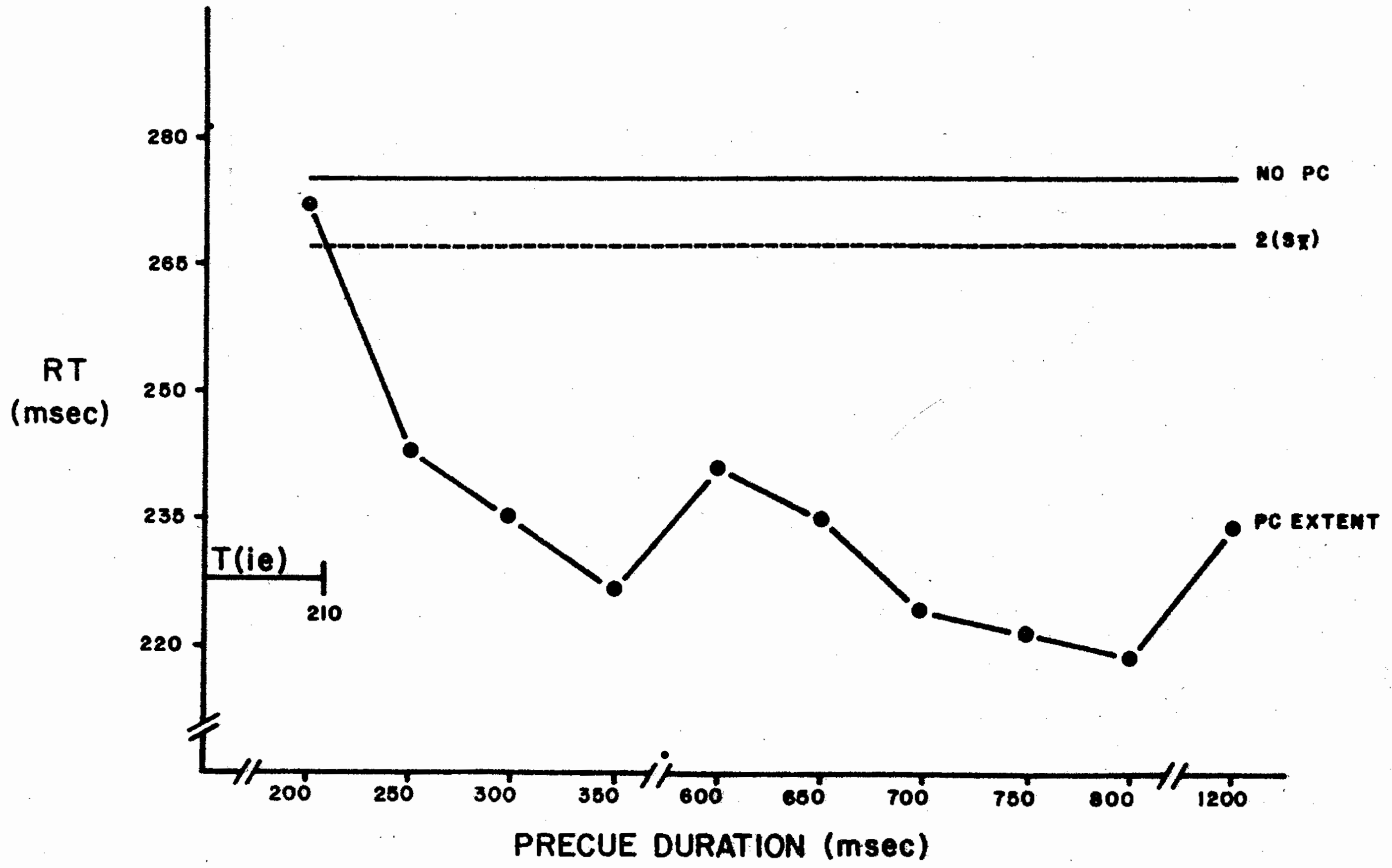


Figure 12. Mean direction preparation time (msec) across precue duration.

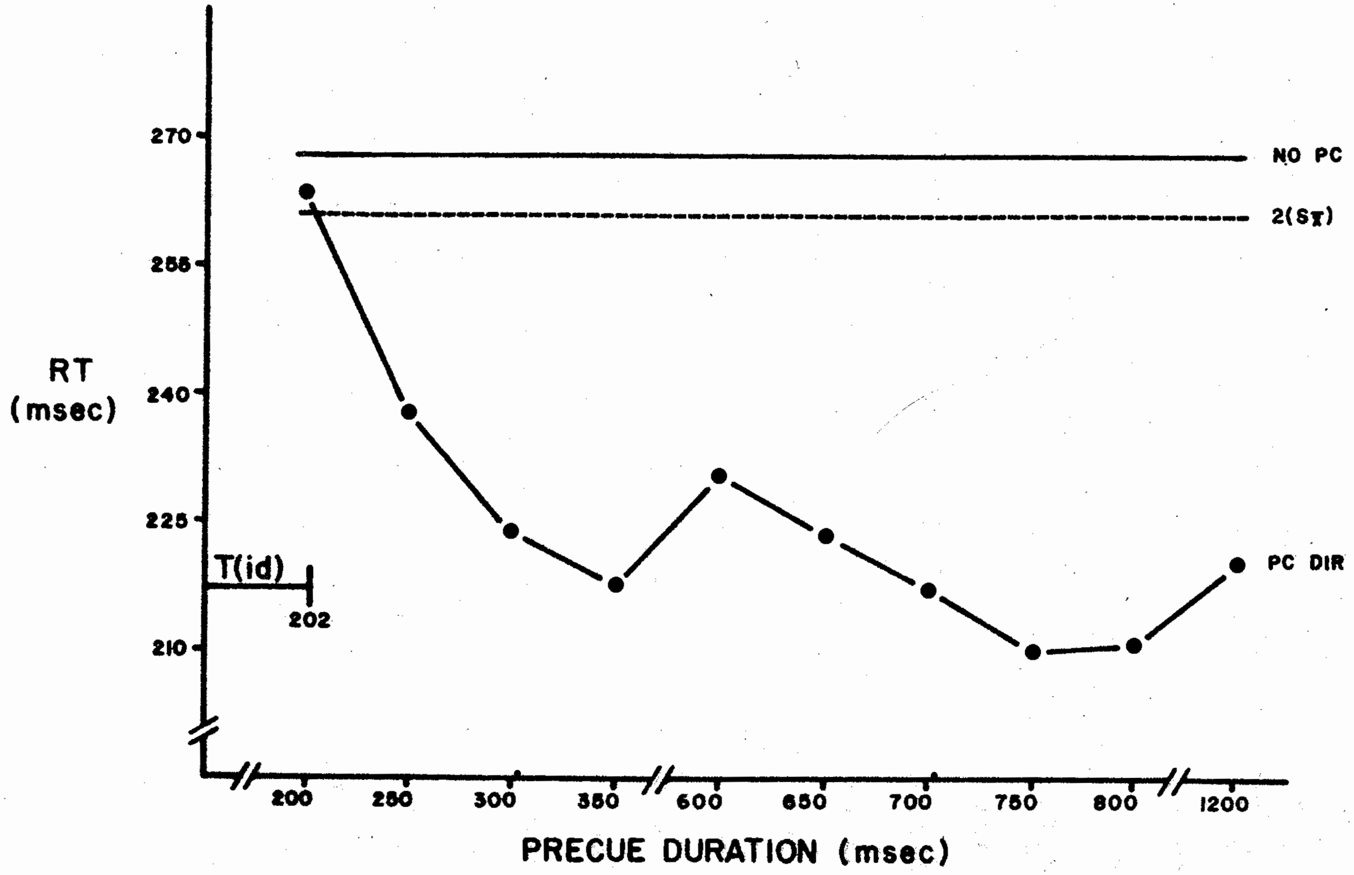


Figure 13. Mean extent preparation time (msec) across precue duration.

One result which was not expected, was the presentation letter by extent interaction. The differences in reaction time for near and distant movements was larger when the response was backwards as opposed to forwards. This result means that the time necessary to program extent was affected by the direction of movement. Accordingly, this suggests that the specification of extent was not done independently of direction. Inspection of the subject means, however, showed that the interaction trend was true for only 3 subjects in the overall analysis and just one subject for precue durations of 700, 750, and 800 msec. Therefore, this interaction is not entirely reflective of the actual subject trends.

<u>Stimulus identification analysis</u>. The mean reaction times for the no precue conditions (prepare direction and extent) are presented in Table 7. The grand mean (270.1) and $S\bar{x}$(3.02) were plotted in both Figure 12 and Figure 13. If one assumes a linear relationship for RT between the precue durations of 200 and 250 msec, the point at which the RT curve crosses two standard errors of the mean is called the stimulus identification time. From the graphs, the stimulus identification times for direction and extent were 202 msec and 210 msec respectively. Table 8 and Table 9 provide the data necessary to calculate the response preparation times for direction and extent. Following the rationale developed in Figure 5, preparation time for direction (22 msec) was the difference between 224 msec (Table 9) and 202

msec (Figure 13). The preparation time for extent (2 msec) was the difference between 212 msec (Table 9) and 210 msec (Figure 12).

From a visual perspective, there was an amazing similarity between Figures 12 and 13. The apparent congruency suggests that direction and extent are prepared in an identical fashion. Although the time courses are slightly different, the processing pattern was very similar for both features.

The estimation of stimulus identification time and response preparation time provided some interesting results. If the logic that went into the experimental paradigm is considered valid, then the primary component of the reaction time is the stimulus encoding process. Estimates of this time were 202 msec and 210 msec. The response preparation component of the reaction time was minimal (2 msec and 22 msec). Why would stimulus identification be the major component? In the environment, stimuli are constantly changing. In order for a person to interact successfully with the environment, the ever changing stimuli must be detected and properly identified. Improper classifications result in a situation where the person will never respond in an appropriate manner. Therefore, stimulus identification is an important component in the response latency period.

The very small estimates (2 msec for extent; 22 msec for direction) of feature preparation time are quite interesting in themselves. They demonstrate the same differential feature preparation effect found in the RT analyses (212 msec vs. 224 msec). These similar and converging results provide a strong case for motor programme construction as a component process.

At this time, it will be useful to explain one of the major problems with the experiment. The mean RT's for a precue duration of 200 msec are the first and only points which approximate the mean RT for the prepare both (no precue) condition (Figure 12 and 13). Another precue duration of 150 msec is necessary to substantiate the reliability of these points. The stimulus identification and response preparation estimates are based on the assumption that mean RT's at the 200 msec precue duration are not different from the program both condition. From the trend apparent in Figure 12 and 13, this assumption should not cause a major problem.

Chapter 6

GENERAL DISCUSSION

The present research was directed towards gaining an understanding of the motor programming process. In this context, Rosenbaum (1980) presented the movement precuing technique as a method for studying this process. Within his theoretical framework, Rosenbaum attempted to explain the motor programme construction process by examination of feature preparation through manipulation of precues. More specifically, it was hypothesized that motor programmes are composed of components which may be identified and examined (e.g., direction preparation). Accordingly, programming could be studied by manipulation of these components.

The movement precuing technique studied these component parts through the measurement of reaction time based on the premise that different amounts of preparation should be reflected by RT changes. Unfortunately, Rosenbaum failed to adequately account for all the non-motor components in his measurements (Goodman & Kelso, 1980; Larish, 1980). Therefore, the results obtained by Rosenbaum need to be re-examined from a different perspective. Accordingly, a new theoretical framework, developed through a variation of the movement precuing technique, was the basis for the present experimentation.

A second problem with the movement precuing approach concerned Fitts' Law (Fitts, 1954). The movement precuing technique necessitated that all movements be performed without vision. Since movement times are important in the evaluation of response programming research (Kerr, 1978), the relationship of MT to ID predicted by Fitts' Law needs to be understood for non-visually guided movements. In executing a movement, it is possible for the response to start before it has been completely prepared (Kerr, 1978). In this case, movement completion is under closed-loop control. An analysis of MT's, when the relationship of MT to ID is known, will reveal whether the movement was completed under closed-loop control. Experiment 1 was designed to determine what the MT-ID relationship may be when vision is removed. A linear relationship was found and used in the interpretation of the MT analyses in the second experiment.

The major function of the second experiment was to examine the motor programme construction process under the new theoretical perspective. An analysis of RT's provided results similar to those of Rosenbaum (1980). A differential programming effect between direction and extent was found and the reaction times for direction preparation were greater than those for extent preparation. The MT analysis demonstrated the results expected from the relationship discovered in Experiment 1. Movement times were longer for responses to the distant targets.

As such, response preparation was completed during the RT and no closed-loop control was involved.

The results of the response programming analysis relate favorably with those of choice reaction time research. Megaw (1972) for example, created a task where extent and direction were varied. The RT when direction was uncertain was longer than when extent was unknown. Similar results were also found by Megaw and Armstrong (1974). In addition, when both direction and extent were unknown, RT was no different than the direction uncertain condition. From these results, Megaw suggested that direction was prepared before movement initiation, while, extent was updated or completed after the movement had begun. Clearly, the present results have some historical validity and current support in this study and its predecessors.

With respect to the estimation of feature preparation times, a differential effect similar to the RT analysis was noted. The preparation time for extent (2 msec) was much shorter than that of direction (22 msec). Estimates of this nature have never been reported before so comparison to related literature cannot be made. Preparation time appears to account for approximately five to ten percent of the total RT. This is an extremely important finding. Small changes in RT, under a response programming paradigm, are reflective of very <u>large</u> changes in the actual preparation process! If RT is the sole measure used in a response programming experiment, the actual changes in the preparation process are underestimated. Therefore, past and current research must be challenged on this masking effect.

The question of parallel/serial processing of information was indirectly tested when the feature preparation times were calculated. If the preparation times had turned out to be negative, serial processing of information could be discounted. Partial support for serial processing was generated, however, when the feature preparation time for direction turned out to be positive. This finding is in line with Theios' (1975) model and breakdown of serial processing. The small preparation time for extent (2 msec) provided minimal to no support for serial processing. A two msec difference across subjects indicated that individual differences were both positive and negative. Two interpretations may be made from this result. First, the near zero preparation time may have been caused by parallel processing of information. Since the body has no receptors for distance, a more likely explanation is that extent is not a programmable feature. In either case, further research is necessary to determine what the role of extent is in response preparation.

Other researchers have also improved the precuing paradigm of Rosenbaum (1978, 1980). Goodman and Kelso (1980) and Larish (1980) failed to find the differential programming effects for direction and extent reported here. The failure to find this effect caused Goodman and Kelso (1980) to propose that the preparation of motor responses cannot be reduced into distinct and separate features. Their reasoning stems from the fact that kinematic features or externally defined movement parameters (e.g., arm, direction, and extent) may be totally different from the internal variables that affect the motor system. Therefore, in terms of feature preparation and externally defined parameters, the separation of a movement into its component parts is an approach whose validity must be questioned.

This view of the response preparation process is similar to the beliefs expressed by Gibson (1966). Gibson perceived the senses to be "perceptual systems" whose individual functioning could not be discerned. This approach has often been termed "wholistic" since the overall system cannot be reduced to the component processes. The position expressed by Goodman and Kelso (in press) is extremely divergent from the views maintained by most researchers. Converging research by a variety of investigators (e.g., Klapp, 1976, 1977; Shaffer, 1978; Siegel, 1977) has demonstrated that movement parameters do affect response preparation; the present findings support the component approach. Accordingly, how can these differing results be explained?

A solution to the differing theoretical positions may be found in the experimental procedures. Until now, investigators employing the precuing technique have failed to recognize the concept of precue duration. There has been no systematic investigation of the effects of constant precue durations on response preparation time. When precue duration remains relatively constant, subjects anticipate the onset of the execution stimulus. Differential feature preparation effects may be missed due to the lowered reaction times. Another problem has been the length of precue duration. Klapp (1976) proposed that short-term memory is the response preparation state. If subjects are required to "wait on" the execution stimulus for an extended period of time, the value of the advance information may be lost through decay (Pepper & Herman, 1970; Stelmach & Kelso, 1975). Although this has never been empirically tested, RT's are hypothesized to be elevated because the precued feature must also be prepared during the latency period. Again, this notion is compatible with Klapp's memory model of response programming.

Although the theoretical positions on response preparation still require clarification, the practical implications of this line of research are not obscure. If response preparation is a component process as the results have implied, then kinematic features which are programmable become increasingly important in the area of motor skill instruction. Therefore, future research should be directed toward discovering the role of other kinematic features (e.g., velocity, force) in response preparation. With this knowledge, the practitioner may direct the performer's attention to the relevent features of a ballistic movement.

In summary, the present experimentation found stimulus identification to be a major component of response latency. Response preparation time, on the other hand, is a minor part of the total reaction time. From a response programming perspective, a differential feature preparation effect was found (i.e., direction took longer to prepare than extent). The feature preparation time estimates mirrored this differential effect. In terms of parallel/serial processing, partial support was generated for the serial processing of information.

In the future, special consideration should be given to the concept of precue duration. By so doing, the role of memory in response programming may be elucidated. If short-term memory is the response preparation state, systematic variation of precue duration, in conjunction with other memory variables, may demonstrate RT effects similar to the properties of short-term memory for movement. Further, additional studies need to be done on the "wholistic" issue regarding programming. Overall, the precuing technique appears to be a powerful tool that needs refinement and careful implementation.

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APPENDIX A-1

Error Rates for Experiment 1

	ID		
	2.9	3.11	3.32
Learning Trials	7.3	8.8	13.9
Test Trials	5.1	3.8	5.4

APPENDIX A-2

Mean movement times (msec) for Experiment 1

	ID		
	2.9	3.11	3.32
Subject 1	352	444	610
Subject 2	301	360	368
Subject 3	372	403	448
Subject 4	428	484	541
Subject 5	347	394	446
Subject 6	339	515	548
Subject 7	397	570	586
Subject 8	351	461	551
Subject 9	388	487	565

APPENDIX B-1

Mean Response Preparation Times (Pilot Data)

Prepare Extent

	200	300	400	500	600	700	800	1200
F								
D	304	265	261	273	248	252	237	229
N	282	227	273	261	246	233	239	221
B								
D	298	249	246	277	241	208	228	212
N	289	230	263	266	244	236	241	231
Prepare Direction								
N								
F	312	247	249	236	243	227	238	224
B	352	294	299	271	258	228	242	234
D								
F	313	291	249	263	237	248	258	243
B	297	278	282	246	253	229	244	263

APPENDIX B-2

Overall MT Analysis of Variance Table: Experiment 2

Distance Precued

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	1922095.00	1	1922095.00	678.40
S	19832.80	7	2333.26	
P	41589.95	1	41589.95	516.69
D	9599.60	1	9599.60	42.22
F	1042.98	9	115.88	1.09
SP	563.44	7	80.49	
SD	1591.69	7	227.39	
PD	153.32	1	153.32	1.69
SF	6675.77	63	105.96	
PF	384.66	9	42.74	0.98
DF	1956.00	9	217.33	5.89
SPD	634.93	7	90.70	
SPF	2722.05	63	43.20	
SDF	2322.55	63	35.86	
PDF	229.38	9	25.48	0.49
SPDF	3235.80	63		

S = Subjects, P = Presentation Letter, D = Direction,
F = Precue Duration

APPENDIX B-3

Overall MT Analysis of Variance Table: Experiment 2

Direction Precued

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	1810130.00	1	1810130.00	636.47
S	19908.00	7	2344.00	
P	20960.21	1	20960.21	39.57
E	71714.56	1	71714.56	471.61
F	2672.82	9	296.98	3.77
SP	3707.52	7	529.65	
SE	1064.44	7	152.06	
PE	102.13	1	102.13	0.46
SF	4960.21	63	73.73	
PF	1151.81	9	129.09	3.07
EF	208.68	9	23.19	0.51
SPE	1531.03	7	218.71	
SPF	2643.03	63	41.95	
SEF	2854.21	63	45.30	
PEF	350.81	9	38.97	1.45
SPEF	1692.58	63	26.86	

S = Subjects, P = Presentation Letter, E = Extent,
F = Precue Duration

APPENDIX B-4

MT Analysis of Variance Table: Experiment 2

Distance Precued

Precue Durations - 700, 750, 800

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	606794.10	1	606794.10	487.50
S	8712.76	7	1244.68	
P	14780.57	1	14780.57	95.47
D	1450.80	1	1450.80	7.61
F	19.70	2	9.85	0.07
SP	1083.68	7	154.81	
SD	1334.32	7	190.62	
PD	1.84	1	1.84	0.01
SF	1957.16	14	139.79	
PF	658.77	2	329.38	2.55
DF	201.52	2	100.76	0.91
SPD	1348.04	7	192.57	
SPF	1802.40	14	128.74	
SDF	1543.47	14	110.24	
PDF	104.47	2	52.23	0.37
SPDF	1973.53	14	140.96	

S = Subjects, P = Presentation Letter, D = Direction,
F = Replicates

APPENDIX B-5

MT Analysis of Variance Table: Experiment 2

Direction Precued

Precue Durations - 700, 750, 800

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	520974.6	1	520974.6	340.98
S	10694.92	7	1527.84	
P	5870.29	1	5870.29	38.97
E	21867.71	1	21867.71	389.07
F	39.29	2	19.64	1.06
SP	1054.35	7	150.62	
SE	393.43	7	56.20	
PE	24.59	1	24.59	0.27
SF	257.77	14	18.41	
PF	17.35	2	8.67	0.20
EF	38.35	2	19.17	0.71
SPE	624.27	7	89.18	
SPF	590.39	14	42.17	
SEF	373.58	14	26.68	
PEF	97.46	2	48.73	2.39
SPEF	285.19	14	20.37	

S = Subjects, P = Presentation Letter, E = Extent,
F = Replicates

APPENDIX B-6

RT Analysis of Variance Table: Experiment 2

Feature Differences

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	9109454.00	1	9109454.00	890.00
S	71647.19	7	10235.31	
P	6460.02	1	6460.03	11.58
T	974.68	3	324.89	0.53
R	1313.51	2	656.75	3.11
SP	3903.66	7	557.66	
ST	12764.50	21	607.83	
PT	3565.48	3	1188.49	2.27
SR	2953.60	14	210.97	
PR	36.34	2	18.17	0.10
TR	612.12	6	102.02	0.87
SPT	10965.26	21	522.15	
SPR	2510.90	14	179.35	
STR	4892.18	42	116.48	
PTR	1263.83	6	210.63	1.63
SPTR	5419.09	42	129.02	

S = Subjects, P = Prepared Feature, T = Target,
R = Replicate.

APPENDIX B-7

RT Analysis of Variance Table: Experiment 2

Distance Precued

Precue Durations - 700. 750, 800

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	4800546.00	1	4800546.00	
S	29966.95	7	29966.95	
P	1496.22	1	1496.22	4.62
D	96.80	1	96.80	0.08
T	879.06	2	439.53	3.58
SP	2266.76	7	323.82	
SD	7918.12	7	1131.16	
PD	0.88	1	0.88	0.01
ST	1715.04	14	122.50	
PT	213.29	2	106.64	0.70
DT	225.38	2	112.69	1.07
SPD	530.63	7	75.80	
SPT	2123.36	14	151.66	
SDT	1462.49	14	104.46	
PDT	1179.98	2	589.99	2.63
SPDT	3131.50	14	223.67	

S = Subjects, P = Presentation Letter, D = Direction,
T = Replicates

APPENDIX B-8

RT Analysis of Variance Table: Experiment 2

Direction Precued

Precue Durations - 700, 750, 800

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	4315376.00	1	4315376.00	662.68
S	45583.91	7	6511.98	
P	526.88	1	526.88	0.49
E	1487.60	1	1487.60	2.12
T	470.80	2	235.40	0.87
SP	7404.33	7	1057.76	
SE	4895.81	7	699.40	
PE	931.76	1	931.76	9.13
ST	3749.61	14	267.82	
PT	79.02	2	39.51	0.52
ET	174.04	2	87.02	1.14
SPE	714.27	7	102.03	
SPT	1056.33	14	75.45	
SET	1060.44	14	75.74	
PET	4.22	2	2.11	0.02
SPET	1478.77	14	105.62	

S = Subjects, P = Presentation Letter, E = Extent,
T = Replicates

APPENDIX B-9

Overall RT Analysis of Variance Table: Experiment 2

Distance Precued

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	17988220.00	1	17988220.00	
S	30041.27	7	30041.27	
P	5623.26	1	5623.26	6.19
D	54.27	1	54.27	0.02
F	65235.00	9	7248.33	6.58
SP	6349.64	7	907.09	
SD	18060.77	7	2580.10	
PD	738.69	1	738.69	2.62
SF	69342.63	63	1100.67	
PF	2252.43	9	250.27	2.40
DF	830.81	9	92.31	0.39
SPD	1972.16	7	281.73	
SPF	6545.75	63	103.90	
SDF	14738.75	63	233.94	
PDF	1927.93	9	214.21	1.38
SPDF	9712.46	63	154.16	

S = Subjects, P = Presentation Letter, D = Direction,
F = Precue Duration

APPENDIX B-10

Overall RT Analysis of Variance Table: Experiment 2

Direction Precued

Source of Variance	Sum of Squares	DF	Mean Square	F
MEAN	16347840.00	1	16347840.00	
S	35331.10	7	35331.10	
P	579.07	1	579.07	0.34
E	11.59	1	11.59	0.01
F	76484.06	9	8498.22	5.70
SP	11835.03	7	1690.71	
SE	7101.07	7	1014.43	
PE	2889.06	1	2889.06	8.98
SF	93889.88	63	1490.31	
PF	1181.12	9	131.23	1.03
EF	4186.45	9	465.15	3.55
SPE	2250.98	7	321.56	
SPF	7993.81	63	126.88	
SEF	8234.56	63	130.70	
PEF	587.80	9	63.31	0.49
SPEF	8317.83	63	132.02	

S = Subjects, P = Presentation Letter, E = Extent,
F = Precue Duration