75-23,150

SIEGEL, Donald Steven, 1947-
THE NATURE AND SIGNIFICANCE OF THE RESPONSE LATENCY ASSOCIATED WITH THE AMENDMENT OF MOVEMENTS OF VARYING COMPLEXITY.

The University of North Carolina at Greensboro, Ed.D., 1975
Education, physical

Xerox University Microfilms, Ann Arbor, Michigan 48106

THE NATURE AND SIGNIFICANCE OF THE RESPONSE LATENCY ASSOCIATED WITH THE AMENDMENT OF MOVEMENTS OF VARYING COMPLEXITY

by

Donald S. Siegel

A Dissertation Submitted to
the Faculty of the Graduate School of
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

Greensboro
1975

Approved by

Dissertation Advisor

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School of The University of North Carolina at Greensboro.

Dissertation Advisor [signature]

Committee Members [signatures]

19th December 1974
Date of Acceptance by Committee

SIEGEL, DONALD S. The Nature and Significance of the Response Latency Associated with the Amendment of Movements of Varying Complexity. (1975) Directed by: Dr. Pearl Berlin. Pp. 122.

This investigation examined variation in the reaction time (RT_2) to the second of two closely paired stimuli when responses were ordered according to relative degree of movement complexity. The sequences included: (a) executing a simple response following a simple response, (b) executing a complex response following a simple response, (c) executing a simple response following a complex response, and (d) executing a complex response following a complex response. The interstimulus intervals were also varied over selected periods of 100, 200, 400, and 800 milliseconds for the purpose of requiring subjects to amend their initial responses at differing points of implementation. An additional question investigated was whether a relationship existed between reaction time measured in a single task situation and RT_2. Measures of reaction time on single and sequential response tasks were generated from 24, female, right-handed volunteers from the University of North Carolina at Greensboro. Subjects were required to attend sessions on five different days.

During Days 1 and 2, each subject was administered 50 simple, and 50 complex response reaction time trials with each hand. The simple response consisted of lifting an index finger from a reaction time key. The complex

response required a series of linear movements and reversals. Both were initiated by the sound of a stimulus buzzer and performed as quickly as possible. On Days 3 to 5 each subject was asked to perform four different blocks of trials having differing sequences of response complexity utilizing the tasks practiced on the first two days.

Data for Days 1 and 2 consisted of mean reaction times for each subject, on each day, for each task. Data for Days 3 to 5 were similarly composed of means for each subject, on each day, for the initial and successive responses in each of the four different tasks. An analysis of the data revealed that the sequence of response complexity was the most important determiner of RT_2. Post-hoc tests among means across all conditions showed that RT_2 was significantly longer when the complex response was first in the sequence. Analogously, it reflected the complexity level of the second response, but to a lesser degree. Fifty-seven percent of the variance in RT_2 was found to be attributable to this factor. Manipulating the interstimulus interval accounted for only two percent of the variation in RT_2. Post-hoc tests revealed that RT_2 was elongated only at the 100 milliseconds interval. Finally, classifying subjects into fast and slow groups on the basis of single reaction time measures accounted for five percent of the variation in RT_2. Each group was found to remain intact across all experimental conditions, thus indicating generality of reaction time speed in the single and sequential tasks used in this experiment.

ACKNOWLEDGMENTS

The writer wishes to extend sincere appreciation to Dr. Pearl Berlin for the enthusiastic support and analytical thinking which she contributed during the planning, implementation, and analysis phases of this investigation.

Acknowledgments are also extended to Dr. Doris McKinney, Dr. Alex McNeill, Dr. Celeste Ulrich, Dr. Robin Pratt, and Dr. John Lawther for the many helpful recommendations offered throughout.

Finally, the writer wishes to acknowledge and thank Sharon Siegel for the numerous insights and thought-provoking suggestions which she generously made, and which were essential to the success of this study.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page
22	Newman-Keuls Test: ISIs at Day 3	111
23	Newman-Keuls Test: ISIs at Day 4	112
24	Newman-Keuls Test: ISIs at Day 5	112
25	Newman-Keuls Test: SRCs at Day 3	113
26	Newman-Keuls Test: SRCs at Day 4	113
27	Newman-Keuls Test: SRCs at Day 5	114
28	Newman-Keuls Test: SRC SS Over Days	114
29	Newman-Keuls Test: SRC SC Over Days	115
30	Newman-Keuls Test: SRC CS Over Days	115
31	Newman-Keuls Test: SRC CC Over Days	116
32	Raw Data for Day 1 and Day 2	118
33	Raw Data: RT_1 Group Means	119
34	Raw Data: RT_2 Group Means	121

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Although the theoretical import of an individual's ability to make corrective movements in various types of responses was recognized as early as Woodworth's classic study in 1899, much still remains unknown concerning this phenomenon. For the most part, skill theoreticians have acknowledged the need to utilize various types of stimuli to guide ongoing responses to their intended conclusions, but they have paid little attention to studying the processes involved when a performer amends one response in favor of another one which has an entirely different goal. In both cases, stimuli are processed by various receptors and transmitted via afferent nerve tracts to control centers in the brain where decisions are made to either maintain or modify the movement as planned. When corrective action is indicated, and the goal of the response is maintained, changes may be made in the executive motor program, or in the inclusion and ordering of subsequent subroutines. However, when the decision calls for a change in goal, different underlying processes would seem to be required. Current movement must be curtailed, a new executive program with different accompanying subroutines organized, and a new response initiated.

Henry's (1960) "memory drum" theory for neuromotor reactions predicts that program changes for a short and uncomplicated response requires a shorter latency than the alteration of a more complicated one. This is anticipated because theory posits that less stored information from the motor memory would have to be withdrawn, and fewer subcenters and channels in the nervous system modified. Although not specifically deduced by Henry, logically it would seem to follow that when another response is called for by the same stimulus signaling the amendment of an immediately previous one, the simple reaction time associated with the initiation of the second movement would be a function of the complexity of each neuromotor program.

Statement of the Problem

Purpose

This study analyzed variations in simple reaction time (RT_2) to a stimulus signaling subjects to amend one response and immediately begin the implementation of another one. In addition, the complexity level for each of the successive responses was systematically ordered so as to test the deduction that a longer latency is associated with the amendment of a more complex motor program. The contribution made by each response to RT_2 was also examined.

The interstimulus interval (ISI), i.e., the period between the first stimulus (S_1) signaling the initial response, and the second stimulus (S_2) signaling curtailment of the first response and commencement of the second one, was also varied over intervals of 100, 200, 400, and 800 milliseconds. The literature consistently supports the notion that RT_2 lengthens progressively as the ISI shortens under about 300 milliseconds. This increase in RT_2 has been attributed to what has become known as the "psychological refractory period" (PRP). By varying both the sequence of response complexity (SRC) and ISI, this study also examined the unique interaction between these factors.

Finally, the relationship between reaction time measures taken in a single task situation and RT_2 was studied. An earlier investigation (Kroll, 1969) demonstrated that subjects who differed initially on simple reaction time and subsequently on initial paired reaction time (RT_1), in a task requiring simple key lifting responses to successive signal stimuli, did not show differences in the absolute magnitude or pattern of response latencies to the second stimulus. This result suggested that the ability to execute responses consecutively when the ISI is short may be a unique skill factor. The present investigation partially replicated and also extended Kroll's study by analyzing differences between relatively fast and slow responders in a single reaction time situation and their RT_2s in a sequential task in which SRC and ISI were varied.

<u>Hypotheses</u>

From past research it was deduced that the reaction time to a stimulus signaling the amendment of one motor plan and the initiation of another one is directly related to the complexity of each. Secondly, it was deduced that when the ISI is 300 milliseconds or less, the reaction time to the second stimulus should be inversely related to the length of the ISI. Finally, it was deduced that no relationship should exist between an individual's reaction time in a single response situation and his response latency to the second of two closely paired stimuli signaling different responses. These deductions gave rise to the following hypotheses:

<u>Hypothesis 1</u>. The reaction time to a stimulus signaling the amendment of a complex motor plan and the initiation of a simple one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

Hypothesis 2. The reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a complex one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

Hypothesis 3. The reaction time to a stimulus signaling the amendment of one motor plan and the initiation of another one increases as the ISI decreases from 400 milliseconds to 200 milliseconds, and from 200 milliseconds to 100 milliseconds.

Hypothesis 4. No difference exists in reaction time to a stimulus signaling amendment of one response and the initiation of another one between those individuals grouped as fast and slow responders in a single, simple reaction time task situation.

Definition of Terms

Amendment of response. Any correction made in an ongoing response, based on intrinsic or extrinsic feedback, intended to either increase the precision of or entirely alter the orginally planned movement.

Ballistic response. Response which is executed as a whole and cannot be influenced by information feedback.

Complex response. Response which requires a comprehensive motor program involving several muscle groups and several specific areas of neuromotor coordination (Henry, 1960). For this study, a complex response was operationally defined as performing a task requiring a series of linear movements with reversals. This response was similar to the one used by Henry (1960).

Executive program. A plan conceived to control the selection and ordering of a sequence of operations.

Intermittency in skill. Discrete intervals at which time corrections can be made in an ongoing response.

Interstimulus interval (ISI). Time period between the onset of one stimulus and the onset of a subsequent one.

Motor program. A plan that can control the selection and ordering of a sequence of operations.

Psychological refractory period. The additional delay observed in the reaction time to the second of two successive signals when the interval separating stimuli is between 50 and 300 milliseconds.

Reaction time. The period between the initiation of a stimulus and the initiation of a response.

Sequence of response complexity (SRC). The ordering of successive responses by the spatial and temporal demands required by each one.

Simple response. Response in which neuromotor coordination centers and pathways are chiefly cerebellar or subcortical without or with minimal cortical involvement (Henry, 1960). For this study, a simple response was operationally defined as lifting a finger from a reaction key at the sound of a simple auditory stimulus.

Skilled response. Complex, intentional action involving a whole chain of sensory, central and motor mechanisms which, through the process of learning, have come to be organized and coordinated in such a way as to achieve predetermined objectives with maximum certainty (Whiting, 1972).

Subroutines. A unitary operation that may be selected and used by an executive program to achieve a specific purpose.

Basic Assumptions

This investigation made the following assumptions:

1. The subjects responded to the stimuli, in all conditions, and on every trial, as quickly as possible.

2. None of the subjects used in this study ever performed the complex task prior to their initial experimental session.

3. Simple reaction time reflected the time taken to process stimuli and organize the implementation of a response.

Scope of the Study

This study investigated the effects of SRC and ISI on RT_2. Additionally, the relationship between an individual's reaction time in a single response situation and his reaction time to the second of two closely paired stimuli signaling different responses was examined.

The boundaries of this inquiry were established, in part, by 24, right-handed, female students, from the population in attendance at the University of North Carolina at Greensboro during the fall semester of 1974, who served as subjects.

The variables in this study consisted of the sequence and complexity of successive responses, and the interval between stimuli signaling the initiation of each reaction. The selected sequences and levels of complexity of successive responses were: (a) executing a complex response following a complex response (CC), (b) executing a simple response following a complex response (CS), (c) executing a complex response following a simple response (SC), and (d) executing a simple response following a simple response (SS). The intervals between stimuli were 100, 200, 400, and 800 milliseconds.

For the purpose of examining the relationship between simple reaction time in a simple task situation and the reaction time to the second of two successive responses, the 24 subjects were grouped on the basis of their reaction times on the simple and complex tasks performed alone. This provided for two levels of reaction time speed, one of which was relatively fast in relation to the other.

Significance of the Study

Many motor skills require a performer to adapt quickly to a changing environment. Usually, this entails amending planned or initiated movements in favor of others having different purposes. In sport, the instances of a successful feint in basketball or a baseball pitcher throwing a "change-up" are examples in which individuals intentionally confuse their opponents, requiring them to amend responses with minimal delay. The skill of driving an automobile also entails the operator reacting to closely ordered stimuli signaling very different responses. Oftentimes the delay in initiating successive adaptive movements may prove fatal!

Experimental studies have confirmed the finding that a confusing display frequently causes performers to select and process inappropriate environmental cues that ultimately lead to incorrect responses within the immediate situation. Amendment of these responses and implementation of correct ones must then be made. However, when the stimuli signaling each are closely paired temporally, the reaction time to the second is found to be inversely related to the ISI, and thus the probability of failure to implement the corrective action in time, to avert erring, is increased.

This investigation, in addition to the factor of ISI, examined the effect of the sequence of complexity of two successive responses on RT_2. Likewise, the interaction between ISI and SRC was analyzed. The relationship between an individual's simple reaction time in a single situation, initial paired reaction time (RT_1), and RT_2 was also considered across all conditions of SRC and ISI.

CHAPTER II

REVIEW OF LITERATURE

The idea that response latency varies with the length of internal processing time is not novel. In fact, Woodworth and Schlosberg (1954) interpreted the measure of reaction time as an index of the complexity of planning future actions. They believed that as internal processes became more complicated, reaction time became longer.

Subsequently, evidence has accumulated in support of their contention. Simple reaction time has been fractionated (Weiss, 1965; Botwinick and Thompson, 1966; Schmidt and Stull, 1970; Wyrick and Duncan, 1974) into premotor and motor components. The literature indicates that the premotor component varies directly with, and accounts for over 50% of the variation observed in total reaction time, while the motor component remains relatively constant over different response conditions. Assuming that the duration of afferent and efferent neural transmission is similar, central processing may be attributed as the locus of variability in delay. Thus, manipulation of the characteristics of a response which a subject is required to execute, logically, should be reflected in the subsequent simple reaction time, since this measure indicates the amount of processing necessary to organize impending motor behavior.

Relationship Between Response Qualities and Simple Reaction Time

Findings supporting the contention that the qualities of a response are related to simple reaction time have been in evidence for quite some time. Freeman (1907), for example, found that when a subject was required to react to a signaling stimulus by making geometric figures, the simple reaction time in initiating these responses varied with the increasing complexity of the representations. The tracing of a pentagon yielded a longer latency than that of a circle, and a circle a longer reaction time than that of a straight line.

Subsequently, Pacaud (1942) partially replicated Freeman's findings. He observed that when a movement resembling a circular path was required to be performed by a subject following a stimulus, the reaction time was longer than when only the response key had to be released.

In a more comprehensive study, Searle and Taylor (1948) examined the relationship between reaction and movement time in a target tracing task. They required subjects to follow a moving line through a narrow slit with a pencil. Searle and Taylor reported that when subjects had to shift their pencils ninety degrees in order to stay on target, reaction time averaged 257 milliseconds, which was well above simple reaction time values for any modality. An additional finding of importance was that movement time was generally shorter than reaction time. This suggested that intermittency existed in the stimulus-response loop, since each movement was brought to a halt before the visual signals of diminishing error had time to effect stopping. The authors interpreted this to mean that certain "open-loop" phases of control were evident during successive corrections, although within the framework of a larger "closed-loop" system. Thus, the reaction time period was thought to deal with the perception of error and the organization of an integrated temporal pattern of nerve impulses which were triggered as a whole unit. In addition, Searle and Taylor suggested that it seemed unlikely that the planned neural pattern could be altered, during its channeling, in response to new stimuli. Hence, it was concluded that a subject does not start out toward a target and stop when the target becomes close, but instead programs an integrated motor pattern which approximately reaches the target. On approaching the goal, a better prediction of error between the initial movement and end point is made, and another movement intended to decrease the anticipated discrepancy is planned and initiated.

This analysis of the internal processes involved in ballistic movements supported the findings of an earlier investigation which was conducted by Woodworth (1899). He performed a similar study in which tracings of various movements were recorded on a rapidly rotating kymograph. From his data, Woodworth suggested that the first impulse of the movements studied contained, in some way, the beginning of the entire movement. Thus, it was concluded that movements performed with such rapidity entailed the programming of spatially and temporally coded nerve impulses which controlled not only activation of the responses, but cessation as well.

In another study intended to investigate the parameters of movement length and direction on reaction and movement time, Brown and Slater-Hammel (1949) observed that reaction time was increased when a subject had to make more than a single finger lifting movement from a reaction key. They reported response latencies for the various distances moved, upon responding, at approximately .25 seconds. This was comparable to the times found by Searle and Taylor (1948) and appreciably longer than the accepted standard of simple auditory or visual reaction times which have been found to be 140 and 180 milliseconds respectively (Woodworth and Schlosberg, 1954). However, Brown and Slater-Hammel found no relationship between variations in the length or direction of the movements used and simple reaction time.

In a later study, Fitts and Peterson (1964) examined the effects of varying response amplitude and terminal accuracy on reaction and movement time. Although reaction time in all tasks approximated 300 milliseconds, which is appreciably greater than simple reaction time to light, no difference in response latency was found across conditions. These findings corroborated those of Searle and Taylor (1948), and Brown and Slater-Hammel (1949), but were not in full agreement with those of Freeman (1907) and Pacaud (1942) in that reaction time did not vary even though the movements did.

Henry (1960) analyzed earlier investigations related to the effect of response complexity on reaction time. He concluded that studies such as the one conducted by Brown and Slater-Hammel (1949) manipulated only length and direction of movements, not complexity. Henry predicted what Freeman (1907) and Pacaud (1942) had already observed, i.e., response latency increases as movements become more complex. Using three different responses, one which required simply releasing a reaction time key, one which demanded moving a hand from a reaction time key and grasping a tennis ball 30 centimeters away, and one which was similar to the previous one, with the exception that more linear movements and reversals were necessary, Henry found statistically significant increases in simple reaction time as the tasks became more complex.

These findings led to Henry's "memory drum" theory for neuromotor reactions. This hypothesis stated that acts of ballistic skill require the calling forth of stored programs from a neuromotor "memory drum" located in the brain. Once initiated, these programs were hypothesized to guide the released outburst of efferent neural impulses through the proper nervous centers, subcenters, and nerve tracts so as to produce the appropriate movements. Thus, the observed increased latency for more complicated movements simply reflected the additional time required to call forth from the "memory drum" and implement a more comprehensive program.

Henry's data were consistent with those of Freeman and Pacaud. In addition, the explanation offered for the phenomenon led to a number of testable deductions. The present study was based on Henry's model, and predicted that when a stimulus occurred which signaled a subject to amend one response and immediately begin the execution of another one, the reaction time of the second movement (RT_2) would reflect the degree of complexity involved in both responses. This seemed logical since preparation for the second response would additionally include the time required to amend the first motor program. For example, in the case of a complex initial program, more subcenters and neural channels would have to be arrested, and thus the reaction time for a subsequent movement would be delayed beyond the time it would take to amend a simpler preceding response.

More recently, Glencross (1972; 1973) reported the relationship between various kinds of responses and their associated reaction times. He concluded from his first investigation (1972) that reaction time was not significantly influenced by whether a movement was short or long, or continuing or reversing. On the other hand, responses performed in more than one plane, including halts, took significantly longer to initiate than simpler finger and hand movements. Subsequently, Glencross (1973) found that performing similar movements against variable forces had no effect on reaction time. However, in contrast to his previous report (1972), he found that reaction time was longer for extended movements, provided that terminal accuracy was required. Again, having to reverse a movement performed in one plane had no significant effect on reaction time. An additional finding was that when bilateral movements were compared to unilateral ones, reaction time was longer. Glencross' overall conclusion was that reaction time is more influenced by variations in the spatial and temporal organization of a movement than it is by the number of motor units that it requires.

In summary, it would seem that results from experiments that have been interpreted to demonstrate either a relationship or the lack of one between reaction time and movement complexity have been inconsistent in their findings. It would seem that complexity may be conceptualized in terms of either amount of movement, i.e., length and force, or the degree of spatial and temporal organization required. In the present study, the complex response was greater on both of these parameters than the simple one, and thus the contention that a sequence of response complexity did in fact exist seemed reasonable.

Sequential Responses and Reaction Time

Since Henry's (1960) "memory drum" theory applied only to ballistic movements (Norrie, 1974), the signal to amend a response (S_2) had to occur within approximately 300 milliseconds from the occurrence of the initial signal (S_1) indicating the subject to begin the first response. When two stimuli requiring different actions by a subject transpire within a temporal interval of approximately this magnitude, an increased reaction time to the second movement has been observed. Hence, this present study not only was designed to account for the effect of the sequence of response complexity (SRC) on RT_2, but also that of variation in the interstimulus interval (ISI).

In essence, the nature and locus of limitations in man's perceptual-motor systems were at issue in the present study. It has become widely accepted that man behaves as an intermittent correction servo in the performance of both continuous and discrete motor tasks. In relation to the delays observed in ongoing performance, which appear to signify intermittency, Craik (1948) stated:

> We must . . . ask ourselves whether this delay is more likely to consist of transmission time of nerve impulses continuously traveling down an immensely long chain of nerve fibers and synapses connecting sensory and motor nerves, or of a "condensed" time lag occuring in one part of the chain. If the first hypothesis were correct, there would seem to be no reason why a continuous stream of incoming impulses should not evoke a continuous stream of motor ones. . . . If, on the other hand, the time lag is caused by the building up of some single "computing" process which then discharges down the motor nerves, we might expect that new sensory impulses entering the brain while this central computing process was going on would either disturb or be hindered from disturbing it by some "switch" system. (p. 147)

Craik later suggested that his ideas could be tested, to some extent, by recording human responses to a series of discrete stimuli presented at various time intervals. He proposed that if a minimum interval was found in which stimuli could not be responded to, this would be evidence for a limited central processing mechanism.

Over the past half century, a relatively large number of investigations have been performed in which the ISI has been manipulated for the purpose of determining the nature and extent of central limitations in executing responses when called forth in a fast, consecutive manner. Telford's (1931) study has been recognized as the first investigation designed to examine these theorized central processes. He generalized from physiological evidence that a refractory phase appeared to be a universal, post-stimulation phenomenon of sensitive tissue. Using a simple response, reaction time task, Telford found that when RT_2 was calculated for ISIs of .5 to 4 seconds, the .5 second ISI resulted in the longest RT_2 latencies. Results from his study led to the conclusion that the inflated RT_2 was indicative of a central refractory period, comparable to the refractory period found in neurons, but of a longer duration. Subsequently, this increased latency has become popularized as the "psychological refractory period." As in the case of simple reaction time however, speculation as to its central locus has been rife, but no theory has yet adequately accounted for the diversity of factual knowledge currently available pertaining to variables which are presumed to influence its magnitude.

Adams (1964) summarized that the British have attempted to explore man as a communications and computer model with a number of input channels, a short- and long-term memory, a limited decision mechanism, and effector apparatus to which the decision processor issues orders. Based on evidence of an increased latency in RT_2, from step-tracking and sequential key lifting or pressing experiments, skill theoreticians such as Craik (1947; 1948), Davis (1956; 1957; 1959; 1962; 1965), and Welford (1952; 1959; 1967) have accepted the concept of intermittency in skill, with the one-channel decision mechanism as its cause. As explained, only one stimulus event at a time may occupy the processor. Subsequent stimuli which follow too soon after earlier ones were theorized to be delayed in some sort of buffer system within the brain until the previous response decisions had been completed and the mechanism cleared.

Data generated by Vince (1947), Poulton (1950), Elithorn and Lawrence (1955), Slater-Hammel (1958), Kay and Weiss (1961), Creamer (1963), Nickerson (1965), Kroll (1969), and Boddy (1972) illustrate the typical finding that when a second stimulus, to which a response must be made, follows an initial one by less than 300 milliseconds, the reaction time to the second stimulus is delayed beyond what would normally be the reaction time period for that response performed alone. In contrast to the single-channel hypothesis, which seems to provide the best fit for the data already available (Bertelson, 1966; Smith, 1967), an alternate explanation for this observed delay in RT_2 has been proposed in terms of temporal expectancy. Hick (1948) and Poulton (1950) appear to be the earliest proponents of this position. Poulton concluded from two experiments that the lack of readiness to respond to S_2, as revealed by an inflated RT_2, may have resulted from either the subject not having prepared adequately, as he was not expecting S_2 so soon after S_1, or that the time interval between stimuli was too short to allow the necessary preparation. To a large degree, this viewpoint is derived from an earlier study performed by Mowrer (1940) in which he found that stimuli occurring before or after a mean preparatory interval were responded to with a greater latency than those occurring at the mean. Smith (1967) related Mowrer's work to the expectancy theorists' position in writing:

> Expectancy theorists, accepting the hypothesis that the mean ISI represents the point of peak expectancy, explain the observed delay in RT_2 by stating that when the ISI between the two stimuli is randomly varied, as is usually done, Ss develop a high expectancy for the second stimulus (S_2) at the mean ISI. Consequently, when very short ISIs are presented, Ss expectancy of S_2 is minimal, with the result that RT_2 is very high. As the ISI increases the expectancy that S_2 will arrive momentarily increases, with a corresponding decline in RT_2. (p. 204)

Adams (1962) tested the expectancy hypothesis of psychological refractoriness by manipulating the statistical structure of the ISI. Whereas single-channel theoreticians regarded refractoriness as a consequence of the absolute values of the ISI, expectancy theorists considered it a function related to the relative distributions for the arrival times of S_2. The results, however, seemed to support both positions in that although the increase in RT_2 was smaller for groups provided with less uncertainty about the occurrence of S_2, the trend of progressively longer latency being associated with decreasing ISIs remained evident.

Creamer (1963) believed that event uncertainty, i.e., the occurrence or nonoccurrence of S_2, would produce delays in RT_2 even when the time certainty of S_2 was constant. Using five different groups of which each had fixed ISIs of 0, 100, 200, 400, and 800 milliseconds, he varied event uncertainty. A sixth group was administered trials in which both variables were uncertain. Creamer concluded from his results that the time certainty groups were comparable to the group in which the arrival of S_2 was varied when RT_2s were contrasted. This led him to summarize that event uncertainty was a more important determiner of RT_2 than was time uncertainty. However, even with fixed ISIs, as in Adams' (1962) study, delays were maximal at the smallest intervals, and decreased as the time between S_1 and S_2 increased.

In a later study, based on the work of Adams (1962) and Creamer (1963), Nickerson (1965) manipulated both the absolute and relative durations of the S_1-S_2 interval in order to study their contributions to RT_2. Four different conditions provided for an overlapping of interval ranges, thus allowing comparisons among intervals with identical absolute, but different relative durations. The four ranges used were 100-500 milliseconds, 300-700 milliseconds, 500-900 milliseconds, and 100-900 milliseconds. Nickerson found, similar to Adams (1962) and Creamer (1963), that RT_2 was a function of both the absolute and relative durations of the intervals used. At all intervals up to 500 milliseconds, RT_2 decreased as the absolute length of the ISI increased. In addition, it was concluded that within conditions, RT_2 was relatively large when the ISI was small relative to the equiprobable alternative durations that it could assume on a particular trial.

Davis (1965) attempted to ultimately determine which explanation, i.e., expectancy of S_2 or that of a one-channel decision processor, was more tenable. He reasoned that those who favor the former attribute the inflated RT_2 times to the distribution of ISIs, while those who support the latter account for refractoriness as a result of blocking a central mechanism by the occurrence of the first stimulus. Davis attempted to resolve this controversy by eliminating the first stimulus. Thus, he instructed subjects to initiate a trial by spontaneously pressing down on a reaction time key and closing a circuit. This event marked the commencement of an interval. The distribution of intervals was kept comparable to the more typical situation when two stimuli were successively presented. Any differences between RT_2 patterns in this experiment and those in which both stimuli occurred were attributed to the effect of the event which initiated the interval rather than the distribution of the ISIs used. When Davis' results were compared to data in which the ISI was begun by S_1, no delays in RT_2 were evident. This seemed to support his contention that psychological refractoriness was essentially caused by a one-channel decision processor which must deal with S_1 before it can process S_2.

These results were in basic agreement with an earlier study performed by Kay and Weiss (1961). They manipulated the degree of regularity in both the preparatory interval to S_1 and the ISI. In addition, they varied conditions so that in some blocks of trials no response was required for S_1. Kay and Weiss found: (a) RT_2 was significantly increased when a response was required to S_1, and (b) RT_2 was greater when the preparatory interval for S_1 was irregular than when the ISI was irregular. These results seemed to indicate that an increase in processing time for S_1 was directly related to the phenomena of psychological refractoriness. Thus, additional support was given to the single-channel decision processing hypothesis.

In a recent study, Boddy (1972) attempted to identify the physiological correlates of psychological refractoriness. He examined the relationship between delays in RT_2 and delays in the prominent nonspecific component of the evoked potential associated with S_2. Boddy made the assumption that this measurement was indicative of the subject's state of attentiveness. Although he was unable to find the hypothesized relationship, i.e., delays in the nonspecific component analogous to delays in RT_2, Boddy did find that in conditions which required subjects to respond to both S_1 and S_2, amplitude, rather than temporal refractoriness was evident in the prominent nonspecific component associated with S_2. He surmised that this finding suggested that the portions of the evoked potential attributable to S_1 and its associated response may have been additive sources in causing the observed delays in RT_2. Boddy's conclusions, thus, seemed to conform to those reached by both Kay and Weiss (1961), and Davis (1965).

In summary, certain generalizations may be made from the findings of studies designed to investigate the theoretical aspects of the "psychological refractory period."

The following statements seem consistent with the literature: (a) RT_2 increases as the ISI decreases below 300 milliseconds, (b) both the absolute and relative durations of the ISI effect RT_2, (c) the amount of processing required for S_1 appears to vary directly with RT_2, and (d) responding to S_1 causes a larger increase in RT_2 than just attending to S_1. In addition, the two most prominent explanations which attempt to account for the delays observed in RT_2 are known as the single-channel decision processing theory, and the expectancy theory. As Welford (1959; 1967), a strong exponent of the former position admitted, the crucial experiments have not yet been done to make one theory more tenable than the other. It seems today that if all the data already accumulated were to be accounted for, delays in RT_2 would seem to vary with circumstances according to principles as yet unknown.

The present study was primarily concerned with the time taken to amend and initiate successive responses of varying complexity. Since the time of the signal to curtail the first response usually occurred at an ISI in which RT_2 has been shown to be prolonged because of the "psychological refractory period," the variation in RT_2 resulting from this phenomenon was considered along with that variation due to SRC.

Complexity of Amended and Successive Movements and RT_2

Few investigations have examined the effect of the complexity of successive paired responses on RT_2. Typically, past research has been done with simple movements which began and ended at approximately the same time. The following studies were exceptions since they utilized tasks of differing degrees of complexity.

Poulton (1950) studied RT_2 in relation to a task which required subjects to trace three successive Vs, as fast as possible, in response to an auditory stimulus. In some conditions a signal was given to stop at a certain point in the configuration, while in other conditions subjects were instructed to disregard the signal. In another condition, subjects had to trace only part of the pattern, but in response to another successive stimulus, continue. Poulton's data showed that stopping the planned response required a median of .25 seconds longer than an ordinary complex graded reaction time. In contrast, the median time for extending the movement was .35 seconds longer. Additionally, he found that if a preparatory signal to extend or amend was provided .6 seconds before the point to alter ongoing movement, RT_2 was eliminated. When the same signal occurred .3 seconds before the stimulus indicating a change in planned action,

RT_2 was found to be intermediately between no preparatory signal and one which sounded .6 seconds prior to S_2. From his data, Poulton concluded that the length of RT_2 was a function of the degree of preparation for future action, and not recovery from a past response.

Vince and Welford (1967), similarly, investigated refractoriness in relation to speeding-up, slowing-down, or entirely arresting an ongoing response. The conditions in this experiment required subjects to trace a line on a revolving drum when a specific line came into view. While subjects were tracing the first line, another line of a different color occasionally appeared at ISIs of 25, 50, 75, 100, 150, 200, 250, and 300 milliseconds, after the occurence of the first line. Different groups had to then speed-up or slow-down their original movement. Contrary to Poulton's finding, the results indicated that longer RT_2s were associated with the group required to slow their response. Vince and Welford explained these findings by reasoning that in order to slow a movement, subjects had to change the pattern of muscular innervation by bringing antagonists into play, while speeding-up merely seemed to require the intensification of the nervous pattern already in operation. As in previous studies, RT_2 increased with a decreasing ISI.

Ten years after Poulton's experiment, Harrison (1960) recognized that the type of response used in studying psychological refractoriness could be a significant factor in the ultimate experimental findings. He deduced from Henry's (1960) "memory drum" theory, which was publicized the same year, that when stimuli are simple and the response movements short and uncomplicated, program changes should be easy to accomplish. However, if a movement was complicated, or required a great deal of neuromotor control, amendment would be difficult. In relation to the "psychological refractory period," he agreed with Davis (1956) who had theorized that the amount of motor control necessary for a particular response was a determiner of RT_2. Harrison, thus, designed an experiment in which he predicted that psychological refractoriness would be totally eliminated if both stimuli and responses were as simple as possible. The first response entailed pressing a button in response to a light, while the second one required moving the same finger a few millimeters, left or right, in response to either of two possible stimulus lights. He used both errors in direction of movement for the second response as well as RT_2 as criteria indicating refractoriness. Harrison concluded from his data that error rates were low for ISIs of 50 to 300 milliseconds, although they became inflated above this range. In contrast, RT_2 varied inversely with the ISIs. The explanation given for these results was that as RT_2 decreased with increasing ISIs errors increased since subjects became tense with the longer ISIs and too eagerly anticipated S_2. This, in turn, led to less accurate judgments of direction and less accurate, but faster responses. Conditions in the experiment also allowed comparison of RT_2s when a response was and was not required of S_1. The shorter latencies in the latter condition led Harrison to conclude, as Poulton had done previously, that the increased RT_2 in the former condition was probably a foreperiod-expectancy phenomenon rather than true central refractoriness. Based on the error rate data, Harrison concluded that he had confirmed his hypothesis concerning simple stimuli, and short and uncomplicated movements.

Although the reasoning for Harrison's hypothesis appeared logical, his conclusions seemed unwarranted. Only simple responses were used, and no comparison was available for examining whether similar results would be evident for a more complicated response.

Subsequently, Henry and Harrison (1961) investigated whether, in contrast to the short movements used in Harrison's (1960) previous study, long ballistic movements would be refractory to alteration. They reasoned that a simple direct movement occurring over a long path, requiring maximal force, is covertly complex. They explained, that not only are contraction of agonists involved in this type of movement, but stabilizers and antagonists. The authors tested the hypothesis which predicted that long movements would be refractory to amendment until the existing motor program associated with it was at least partially read out of neuromotor memory. To test this deduction, subjects were required to execute an arm swing over a distance of 91 centimeters as fast and as forcefully as possible in response to a visual stimulus (S_1). However, 58% of the trials were accompanied by another visual signal (S_2), which followed S_1 at ISIs of .10, .19, .27, and .35 seconds. The results were somewhat ambiguous as Henry and Harrison concluded from their data that, when S_2 occurred at an ISI of .10 or .19 seconds, deceleration of the movement was evident, but reversal was impossible. This was interpreted as being substantiation for their hypothesis of refractoriness for long movements. Again, RT_2 increased with decreasing ISIs.

In an attempt to clarify the previous research, Williams (1971a) replicated and more precisely analyzed the differing concepts of refractoriness that had been used by Henry and Harrison (1961). He pointed out that for the earlier experiment refractoriness had been defined in terms of error, i.e., inability to amend the movement in time to avoid hitting a target, rather than in terms of inflated RT_2 values. Williams examined both dependent measures and found that each led to different conclusions. When S_2 occurred early in the response, fewer errors were made in stopping the movement before the end point, but at the same time, RT_2 increased with smaller ISIs. His conclusion that experiments must distinguish between these two definitions of refractoriness was well taken, in that one is based on the characteristics of the movement response while the other is concerned with central processing.

In summary, it appears that although various movements have been used in studying the processes involved in executing corrective responses, no single investigation has systematically examined SRC in relation to ISI. Additionally, previous studies (Poulton, 1950; Henry and Harrison, 1961; Williams, 1971a; Williams, 1971b) have used initial and successive responses performed by a single anatomical structure. Consequently, this strategy may have inadvertently attenuated the precision of findings by peripheral confounding resulting from such factors as limb inertia.

The present study utilized contralateral limbs to execute separate responses varied according to SRC. ISIs were also varied for the purpose of examining the effect of the occurrence of S_2 on amendment of simple and complex motor programs at varying degrees of execution. The dependent variable selected was RT_2, which from past research seemed to be a valid indicator of the central processing time involved in responding to S_2 after initially responding to S_1.

Simple Reaction Time and RT_2

Some of the previously reviewed experiments in which amending behavior was examined mentioned that intersubject variation across different conditions was significant (Boddy, 1972; Vince and Weldord, 1967; Davis, 1962). Kroll (1969) indicated that such information has, for the most part, gone unnoticed. However, the import of such findings, as he suggested, is considerable since the single-channel theory of psychological refractoriness holds that when S_2 occurs before the response to S_1 (RT_1), RT_2 and RT_1 will be directly related by the formula: $RT_2 = RT_1 + RT_N - ISI$, where RT_N is equal to the single, simple reaction time of the second response (Davis, 1956). According to this formula, Kroll surmised that subjects with the same simple reaction time should exhibit identical delay patterns in the sequential response situation.

Hence, he conducted an experiment to investigate whether, in fact, individuals who differed initially on RT_1, differed subsequently when RT_2 was analyzed. After classifying individuals into relatively fast and slow groups, based on single, simple reaction time, he ran all subjects through a sequential response task in which ISIs ranged from 50 to 1000 milliseconds. Kroll concluded, from his data, that no difference existed in the absolute magnitude or pattern of RT_2 between groups. This finding was not only in serious conflict with the single-channel processing theory, but suggested that a subject's ability to perform fast, consecutive, paired responses might be a unique skill factor.

The present study, in addition to examining the effects of varying SRC and ISI on RT_2, attempted to replicate Kroll's experiment by dividing subjects into relatively fast and slow groups based on separate, single measures of reaction time. The relationship between this hypothesized speed factor and RT_2 was analyzed across all conditions.

CHAPTER III

PROCEDURES

This experiment was conducted for the purpose of studying the effects of varying the ISI and SRC on RT_2. In addition, the relationship among an individual's simple reaction time in a single situation, initial paired reaction time (RT_1), and RT_2 was examined across all conditions of SRC and ISI. For the purpose of assessing the effects of these factors on RT_2 the following procedures were utilized.

Subjects

Data for this investigation were generated from 24, female, right-handed subjects who volunteered from the population of students in attendance at the University of North Carolina at Greensboro during the fall semester of 1974. Their ages ranged from 18 years to 35 years, with a mean of 19.7 and a standard deviation of 3.8 years.

All subjects were briefed on the tasks which they would be asked to perform prior to their initial sessions. This was done for the purpose of assuring them that no deception or aversive conditions would prevail during testing. On the first and third days of the experiment, each subject was read standard instructions (Appendix A) pertaining to the movements that they were required to perform. The experimenter then demonstrated the responses and answered questions. On Day 5 each subject was verbally debriefed and given a written explanation (Appendix A) related to the theoretical aspects of this study.

Stimuli

In all conditions, the stimuli signaling the subject to execute a response consisted of a signal, lasting 30 milliseconds, generated from two 12 volt General Electric buzzers, which were wired in parallel. In addition, throughout this investigation, a red warning signal located on a partition directly in front of the subject, 26 centimeters above the table top upon which test apparatus were located, occurred prior to the initiation of each trial. This signal served as a warning to subjects that their index finger(s) should be placed upon the appropriate key(s), closing the contact(s). The preparatory interval for all days was presented in a constrained random order, i.e., each interval, 1, 2, 3, and 4 seconds, occurred an equal number of times in a block of trials.

Responses

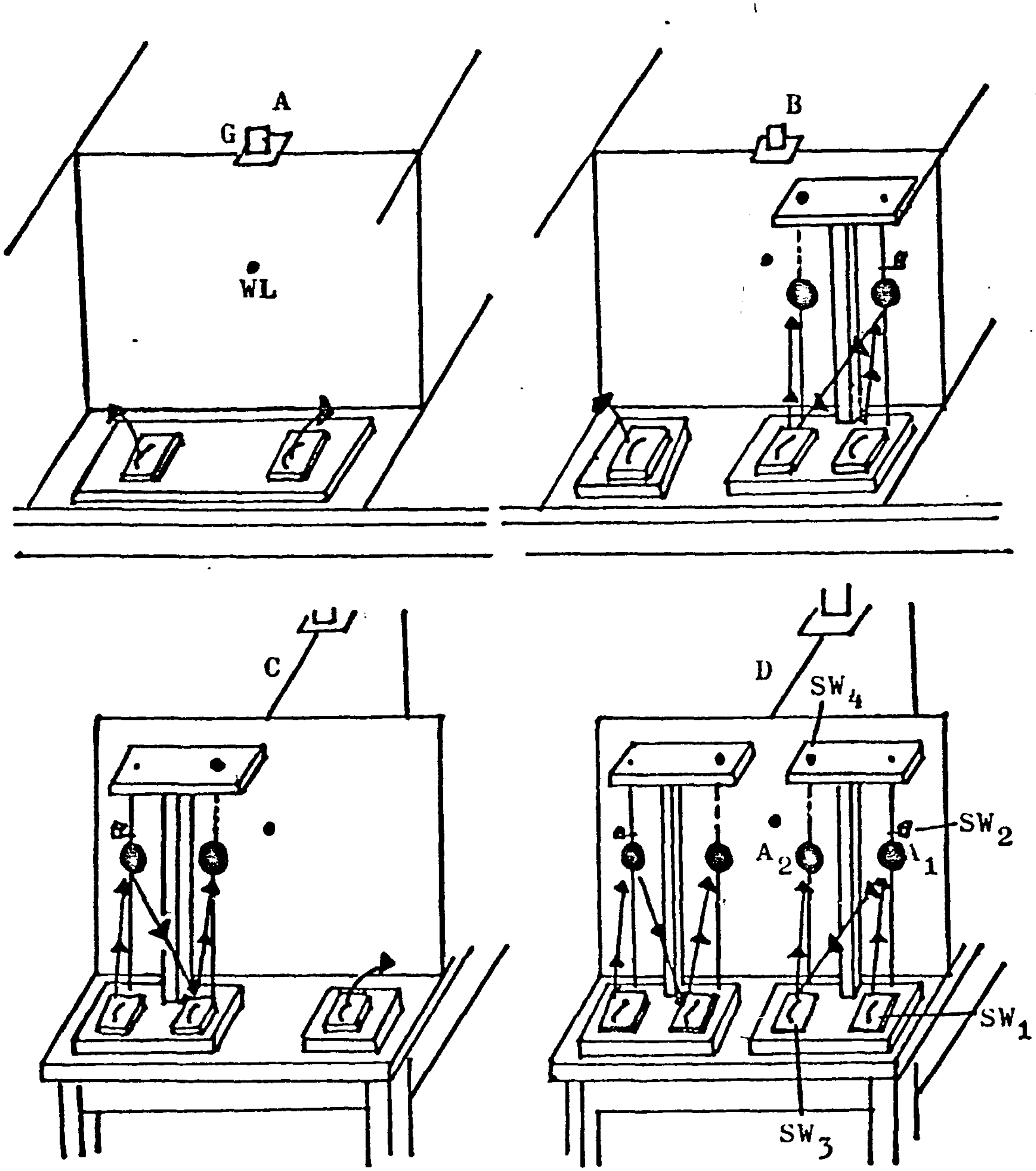
The responses which subjects were required to perform during this investigation were designed to be as much like those used by Henry (1960) as possible. Since data generated from these responses were used in formulating the "memory drum" theory for neuromotor control of well practiced movements, it seemed that they also could be used to test subsequent theoretical deductions.

The complex response for this study consisted of the motor pattern that Henry adapted from Howell (1953), and labeled C. It entailed a subject, while seated, to move her hand off of a reaction time switch (SW_1), reaching forward 30 centimeters, and upward 15 centimeters to strike a tennis ball (A_1) with the back of her hand, closing dummy switch (SW_2), reversing direction to go diagonally back to another dummy switch (SW_3) on the baseboard, located parallel and 30 centimeters to the left or right of SW_1, and then reversing direction again and going upward 15 centimeters and forward 30 centimeters to pull down tennis ball A_2, which was attached by a cord to another dummy switch (SW_4). The apparatus required for the left- and right-handed responses are diagrammed in Figure 1 on page 39.

The simple response consisted of the subject lifting her index finger off of a reaction time key, at the sound of the appropriate stimulus. This response is also illustrated in Figure 1.

Equipment

The experimental equipment consisted of 4 complex response apparatus, and 4 simple reaction time keys. These were distributed among conditions as follows: (a) condition 1 (SS) -- 2 simple reaction time keys, (b) condition 2



A-Simple-Simple
B-Simple-Complex
C-Complex-Simple
D-Complex-Complex
A_1-First Tennis Ball Hit
A_2-Second Tennis Ball Hit
SW_1-Switch
SW_2-Dummy Switch
SW_3-Dummy Switch
SW_4-Dummy Switch
G-Buzzer
WL-Warning Light

Figure 1. Experimental apparatus.

(SC) -- 1 simple reaction time key for the initial response and a complex apparatus for the second one, (c) condition 3 (CS) -- 1 complex apparatus for the left hand and a simple reaction time key for the right one, and (d) condition 4 (CC) -- 2 complex apparatus. Diagrams of each condition are represented in Figure 1 on page 39.

All SRC conditions were located on a table 90 centimeters by 150 centimeters, and separated by plywood partitions. The equipment used to set intervals and measure RT_1 and RT_2 was located in a room which was adjacent to the one in which the subject performed. Figure 2 on page 41 illustrates the testing situation.

<u>Wiring</u>

In order to control the length of the foreperiod, and the initiation and duration of stimuli, four interval timers were used. Interval Timer 1 started the warning signal, which was a visual stimulus mounted between apparatus in each condition and 26 centimeters from the table top. In addition, Timer 1, after a variable preparatory interval, ranging from 1-4 seconds, initiated interval Timers 2 and 3. The onset of Timer 3 caused S_1 to buzz for 30 milliseconds, while Timer 2 began an ISI of either 100, 200, 400, or 800 milliseconds. Timer 4 was connected to Timer 2, and set off S_2 at the end of the ISI. Timers 1, 3, and 4

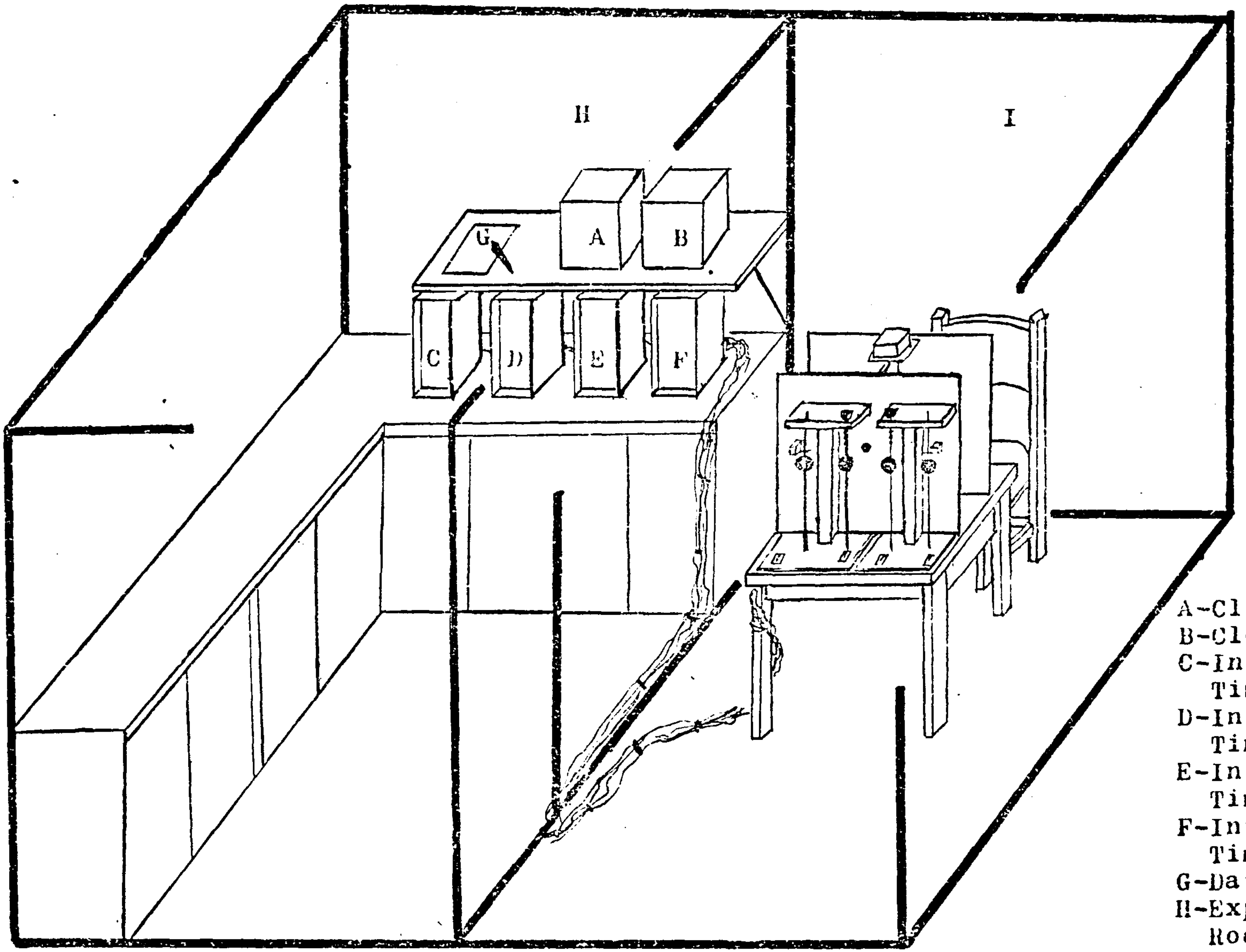


Figure 2. Testing situation.

A-Clock 1
B-Clock 2
C-Interval Timer 1
D-Interval Timer 2
E-Interval Timer 3
F-Inteval Timer 4
G-Data Sheet
H-Experimenter Room
I-Subject Room

were Hunter interval timers, model 111B, while Timer 2 was manufactured by Lafayette Electronics, model number 50013.

Clock 1 was attached to Timer 3, and was initiated simultaneously with S_1, while Clock 2 was wired to Timer 4, and began with the onset of S_2. The initiation of movement by the left hand resulted in stopping Clock 1, while a similar movement of the right hand stopped Clock 2.

All initial, left-handed reaction time keys were wired in parallel, and connected to Clock 1, while right-handed keys were identically wired and attached to Clock 2. The interval between the initiation of a stimulus and the releasing of an appropriate key was recorded as reaction time. Both clocks were model 54014 from Lafayette Electronics. A diagram illustrating the connections of the circuit is located in Figure 3 on page 43.

Data sheets for recording RT_1 and RT_2 for each subject, contained two sets of uniquely randomized intervals for each condition. The experimenter referred to these prerecorded preparatory intervals and ISIs on each trial, and manually set the necessary dials. In addition, data on each trial were recorded on these forms (Appendix A).

Experimental Conditions

This study required five experimental sessions for each subject. Although every attempt was made to order these sessions for consecutive days and similar daily times,

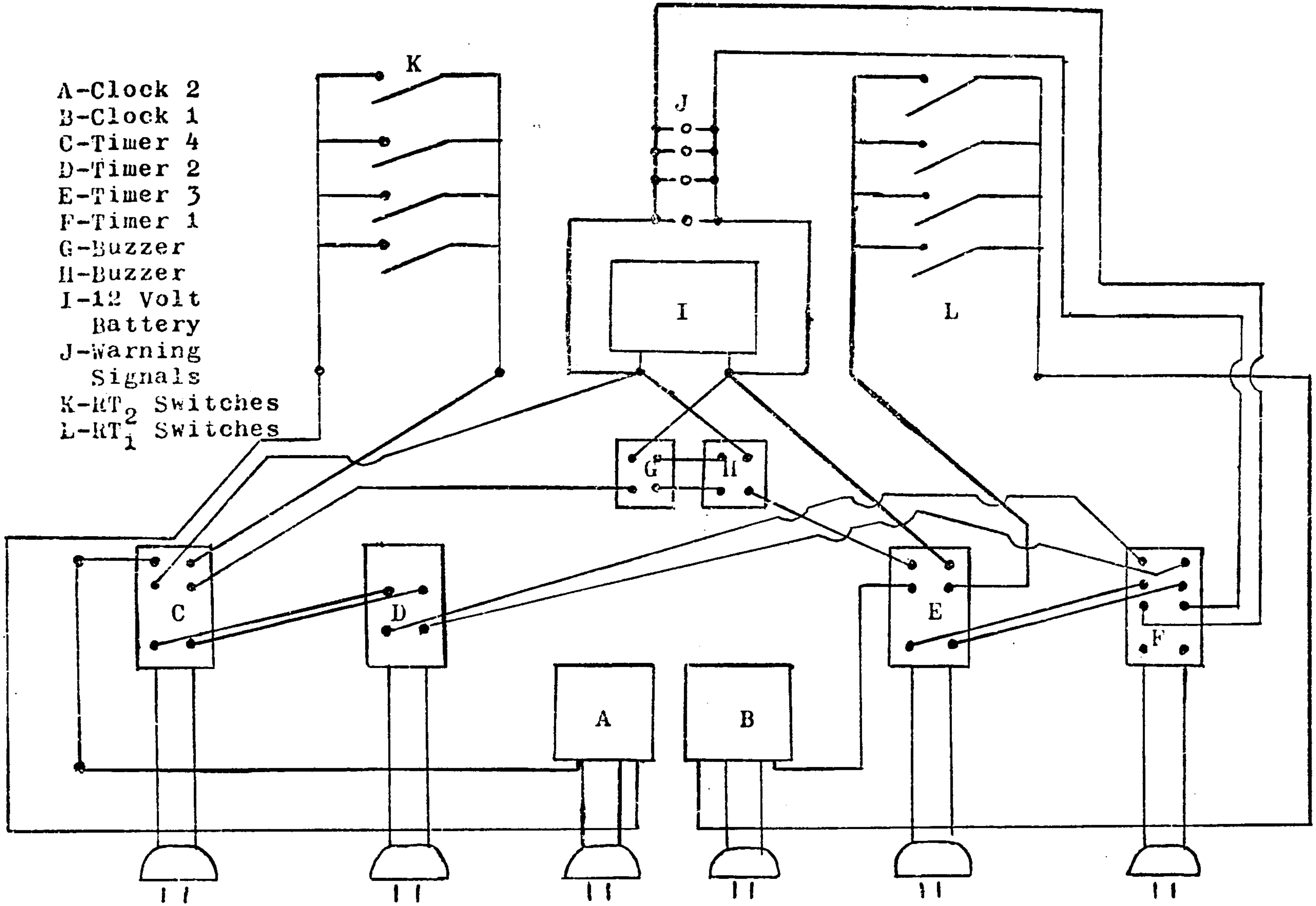


Figure 3. Non-technical schematic of wiring.

laboratory availability and subject schedules did not always coincide. However, no subject completed all five sessions over a period longer than eight days, and all performed daily within two hours of the time of their initial visit.

Days 1 and 2

During Days 1 and 2 each subject was administered 50 simple and 50 complex response reaction time trials with each hand. These 200 trials were grouped into blocks of 25 and included 5 randomly placed catch trials, i.e., trials upon which the stimulus did not occur. The eight blocks were randomly assigned to subjects. This procedure allowed for each subject to perform two blocks of each task with each hand, on each of the first two days. Ten seconds were permitted between the end of one trial and the beginning of the next, while a two minute rest period was given between blocks. Hence, for each of the first two days, 40 trials for simple and 40 trials for complex response reaction time were available for calculating means, for each hand, in each condition.

These procedures were used to attain a well practiced measure of reaction time. On the basis of Kroll's (1969) study, and that of Slater-Hammel (1958), optimal measures of simple reaction time were found during the first two days of practice, thus the methods used in this experiment seemed sufficient to guarantee well practiced measures of reaction time.

Days 3-5

On Day 3, subjects were read a different set of standard instructions (Appendix A) related to the tasks which they would be asked to perform over the next three sessions. Each subject was required to perform four different blocks of trials having different sequences of response complexity utilizing the tasks practiced on the first two days. Block 1 entailed executing the simple response following the simple response (SS), Block 2, executing the complex response following the simple response (SC), Block 3, executing the simple response following the complex response (CS), and Block 4, executing the complex response following the complex response (CC). Each block consisted of 45 trails containing 5 randomly assigned catch trials for the second, right-handed response. No catch trials were alloted to the initial, left-handed response. In all blocks, and over all trials, the left hand responded to the initial stimulus (S_1), while the right hand responded to the second stimulus (S_2).

The four SRC blocks were assigned randomly to each subject, on each of the three days. In addition, ISIs of 100, 200, 400, and 800 milliseconds were distributed within each SRC block in a constrained random order. These intervals were primarily selected for the purpose of having S_2 occur at various points of the initial response, while also covering the range of ISIs in which psychological refractoriness has been found. The 800 milliseconds ISI acted as a control condition, since under all other levels of ISI, subjects were required to amend their motor plans prior to completion of the entire first response. It therefore seemed that if subjects always had to amend their initial programs, they may have decided, after several trials, to only plan the initial portion of the first response. Henry's (1960) data for the complex movement time showed that college women had a mean movement time of 552 milliseconds, with a standard deviation of 95 milliseconds. Hence, inclusion of the 800 milliseconds ISI appeared sufficient to insure completion of the initial complex task on approximately 25% of the trials within the CS and CC blocks.

Ten seconds were allotted between the end of one trial and the beginning of the next one, while a two minute rest period was permitted between SRC blocks. In addition, five practice trials, on each day, preceded the 45 experimental trials in each SRC condition. Figure 4 on page 47 illustrates the overall design used in the experiment.

	SRC_1				SRC_2				SRC_3				SRC_4			
	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
S_1																
.																
.																
.																
.																
.																
.																
.																
.																
.																
S_{24}																

SRC_1 = Simple-Simple I_1 = ISI-100 milliseconds

SRC_2 = Simple-Complex I_2 = ISI-200 milliseconds

SRC_3 = Complex-Simple I_3 = ISI-400 milliseconds

SRC_4 = Complex-Complex I_4 = ISI-800 milliseconds

S_1-S_{24} = Subjects

Figure 4. Experimental design.

For each session, the data consisted of arithmetic means for RT_1 and RT_2, in each condition. Hence, 40 trials were available in calculating these measures at every SRC and ISI level, while 10 values were utilized in performing the calculation in each cell representing an interaction between factors.

Treatment of Data

Grouping the Subjects

A repeated measures, multivariate analysis of variance, using mean day, right-handed reaction time for both simple and complex response tasks was performed to determine whether a difference existed between overall daily performance on Day 1 and 2. This analysis was done for the purpose of deciding upon which of the first two day's scores, taken as a composite, represented the faster, and thus, better practiced measure of reaction time. The scores representing the fastest daily performance were then analyzed to determine which of the two variables had the higher correlation coefficient with the derived canonical variable. Based on this comparison, the variable found to be the best discriminator between days was used as the criterion variable for dividing subjects into two groups of 12 each, which were relatively fast and slow on this measure. A discriminant analysis was then performed using both measures of reaction time, on the faster day, to test whether the groupings, which were based on a single predictor variable, remained intact when the less discriminating variable was simultaneously considered. All of the above analyses were computed using computer programs from the Statistical Analysis System (Service, 1972).

<u>Analysis of RT_2</u>

An analysis of variance for repeated measures, using RT_2 as the dependent variable was run via computer program 08V of the Biomedical Series of Computer Programs (Dixon, 1973). Previously determined fast and slow groups of subjects were nested in levels of speed, and completely crossed within the factors of SRC, ISI, and days. The analysis of variance followed the form taken by the experimental design located in Figure 4, on page 47.

All factors relevant to the purposes of this study, which were significant at the .05 probability level, were then analyzed using the Newman-Keuls post-hoc test for multiple comparisons among treatment means. Graphs were also constructed to aid in the interpretation of the data.

Finally, the percentage of variance attributable to each significant effect was calculated via Omega Square (Hays, 1963). This statistic provided a means for comparing the relative strength of each factor in determining RT_2.

CHAPTER IV

DATA ANALYSIS AND DISCUSSION

This study examined the effects of manipulating tho SRC and ISI on RT_2. In addition, the question of whether an individual's simple reaction time in a single situation, initial paired reaction time, and RT_2 were in any way related across all conditions of SRC and ISI was investigated. Hence, the dependent measures included single, simple and complex response reaction times, generated during the first two days, and RT_1 and RT_2 taken over the following three days. Data for these dependent variables were produced by 24, female, right-handed volunteers.

Assigning the Subjects into Fast and Slow Groups

Prior to performing the multivariate analysis of variance for determining whether single, simple and complex response reaction times, considered as a composite indication of speed, decreased significantly over the first two days, descriptive data related to each task were calculated. Tables 1 and 2 on page 51 collates these obtained data.

Indices reveal that all reaction time measures decreased from Day 1 to Day 2, while all correlations increased. This suggested that subjects, by becoming faster on Day 2, benefitted from the first day's practice. Additionally, the increase in all correlations indicated that some of the

Table 1

Descriptive Data: Day 1

Response	Mean	SD	Pearson Coorelation			
			SR	SL	CR	CL
SR	153 ms.	25 ms.	-	.68*	.40	.52*
SL	153 ms.	24 ms.		-	.34	.40
CR	219 ms.	30 ms.			-	.67*
CL	224 ms.	34 ms.				-

Note. SR=Simple Response-Right Hand
SL=Simple Response-Left Hand
CR=Complex Response-Right Hand
CL=Complex Response-Left Hand

*$p < .01$

Table 2

Descriptive Data: Day 2

Response	Mean	SD	Pearson Coorelation			
			SR	SL	CR	CL
SR	141 ms.	29 ms.	-	.86*	.70*	.80*
SL	138 ms.	28 ms.		-	.59*	.66*
CR	195 ms.	31 ms.			-	.87*
CL	202 ms.	34 ms.				-

Note. SR=Simple Response-Right Hand
SL=Simple Response-Left Hand
CR=Complex Response-Right Hand
CL=Complex Response-Left Hand

*$p < .01$

extraneous variance among the tasks had dropped out. It was, thus, assumed that the common variance on Day 2 more accurately represented a general speed factor among tasks. It must be noted that the simple reaction time values in this study were very similar to those given by Woodworth and Schlosberg (1954). The complex response means approximated Henry's (1960) data. These findings were in accord with the "memory drum" deduction of an increase in response latency for more complicated movements.

Multivariate Analysis of Variance to Determine Day Effect

Since the primary dependent variable investigated for the sequential tasks on Days 3 to 5 was the mean reaction time for the second, right-handed response, the measures used in the multivariate analysis of variance to test improvement in reaction time over the first two days were mean reaction time values for each of the 24 subjects for their daily right-handed, simple and complex response reaction times. This analysis was indicated by the presence of a Pearson product-moment correlation coefficient of .64, $p < .01$, between these variables over both days. Unlike analysis of variance, which would test each variable separately and lead to inaccurate probability statements in determining the significance of an F ratio, multivariate analysis of variance takes into account the relatedness of the dependent measures and determines the appropriate probability distribution for testing different effects while considering both variables simultaneously (Newell and Martens, 1974). In addition, correlations were run between each dependent variable and the calculated canonical variable.

The results yielded an approximate *F* value of 9.58 which was significant at the .01 probability level. This statistic indicated that Day 2 values, when considered simultaneously, were faster than Day 1 measures. This supported the descriptive data in Tables 1 and 2.

The correlation coefficients between the canonical variable and each dependent measure were .46 and .99 respectively, for simple and complex response reaction times. This suggested that complex response reaction time was a more powerful discriminator between days than simple response reaction time, as it accounted for 98% of the variance in the canonical variable. This finding was in contrast to only 21% accounted for by simple response reaction time.

<u>Discriminant Analysis for Verifying Speed Classifications</u>

Since complex response reaction time was found to be the better discriminator variable between days, its median value on Day 2 was determined, and used as the criterion for dividing the 24 subjects into groups. To determine whether these fast and slow group classifications remained intact when both variables, i.e., simple and complex response reaction times for Day 2, were used together as group discriminators, a discriminant analysis was performed. This procedure based each subject's classificatory status on the generalized squared distance to each group's mean composite variable (Rao, 1965). The results affirmed the assignment of all subjects to their respective original group. Table 3, located below, provides data about the original group of each subject; the group to which she was classified, the generalized squared distances to each group, and their associated probabilities.

Table 3

Discriminant Analysis

Subject	Classified by CR	Classified by Discriminant Analysis	Generalized Squared Distance to Fast Group/ Probability	Generalized Squared Distance to Slow Group/ Probability
1	Slow	Slow	25.7152 .0037	14.5232 .9963
2	Fast	Fast	13.6016 .9959	24.6100 .0041
3	Fast	Fast	16.6102 .8866	20.7232 .1134

Table 3--Continued

Subject	Classified by CR	Classified by Discriminant Analysis	Generalized Squared Distance to Fast Group/ Probability	Generalized Squared Distance to Slow Group/ Probability
4	Fast	Fast	16.9203 .9977	29.0987 .0023
5	Fast	Fast	11.8298 .9525	17.8272 .0475
6	Fast	Fast	12.3485 .9041	16.8359 .0959
7	Fast	Fast	12.1201 .9925	21.9016 .0075
8	Slow	Slow	63.4903 .0000	20.5626 1.0000
9	Slow	Slow	36.1939 .0000	16.0917 1.0000
10	Fast	Fast	12.7336 .9191	17.5936 .0809
11	Slow	Slow	27.7142 .0022	15.4396 .9978
12	Fast	Fast	13.1735 .8520	16.6740 .1480
13	Slow	Slow	15.3547 .4461	14.9216 .5539
14	Slow	Slow	16.4403 .3234	14.9644 .6766
15	Slow	Slow	38.2437 .0000	16.9269 1.0000
16	Fast	Fast	13.5406 .9107	18.1840 .0893

Table 3--Continued

Subject	Classified by CR	Classified by Discriminant Analysis	Generalized Squared Distance to Fast Group/ Probability	Generalized Squared Distance to Slow Group/ Probability
17	Slow	Slow	38.4369 .0000	16.0950 1.0000
18	Slow	Slow	22.0527 .1227	18.1192 .8773
19	Fast	Fast	12.4456 .9735	19.6567 .0265
20	Fast	Fast	12.6646 .9605	19.0446 .0395
21	Slow	Slow	23.5931 .0099	14.3772 .9901
22	Slow	Slow	26.0251 .0036	14.7513 .9964
23	Fast	Fast	13.0945 .8254	16.2013 .1746
24	Slow	Slow	23.4077 .0282	16.3285 .9718

Table 4, located on page 57, shows the collated descriptive data for each group. It reveals that the slow group not only had higher reaction times on both responses, but greater variability. Additionally, the slow group had a low and insignificant correlation between tasks. These two indexes, when contrasted with those of the fast group, may indicate that, whereas the fast group was able to use innate speed to succeed at the tasks, the slow group had to resort to a variety of other strategies.

Table 4

Descriptive Data for Fast and Slow Groups[a]

Group	CR Mean	CR SD	SR Mean	SR SD	Pearson Correlation
Fast N=12	171	16	123	15	.73*
Slow N=12	219	23	160	29	.28

[a]In milliseconds

*$p < .01$

All the analyses used in categorizing the 24 subjects into fast and slow speed groups were run using computer programs from the Statistical Analysis System (Service, 1972).

Analysis of Variance Using RT_2 as the Dependent Variable

An analysis of variance was then run in order to examine the effects of varying the SRC and ISI on RT_2. Fast and slow groups of subjects were nested in levels of speed, while crossed within SRC, ISI, and days. The results of the analysis are located in Table 5, on page 58.

Table 5

Analysis of Variance

Source	SS	df	MS	F
Between Ss				
A	510133.8	1	510133.8	11.7785*
Ss(A)	952833.3	22	43310.6	
Within Ss				
C	5364512.0	3	1788170.0	208.2353*
AC	36866.0	3	12288.7	1.4310
CSs(A)	566758.8	66	8587.3	
I	208854.7	3	69618.2	22.1046*
AI	11613.2	3	3871.1	1.2291
ISs(A)	207866.6	66	3149.5	
D	132628.4	2	66314.2	22.2129*
AD	8040.8	2	4020.4	1.3467
DSs(A)	131356.9	44	2985.4	
CI	181552.3	9	20172.5	19.6995*
ACI	11981.8	9	1331.3	1.3001
CISs(A)	202753.6	198	1024.0	
DI	51518.2	6	8586.4	8.7425*
ADI	1937.9	6	322.9	.3289
DISs(A)	129642.1	132	982.1	
DC	53928.0	6	8988.0	3.7088*
ADC	8188.2	6	1364.7	.5631
DCSs(A)	319892.1	132	2423.4	
DCI	28729.8	18	1596.1	2.6766*
ADCI	10055.1	18	558.6	.9368
DCISs(A)	236140.8	396	596.3	

Note. A=speed, C=SRC, I=ISI, D=days, Ss=subjects, ( )=Nesting

*$p < .01$

Sequence of Response Complexity

The analysis of variance reveals that SRC had a very significant effect on RT_2. The SRC F value was 208.2353, which for 3 and 66 df was significant beyond the .01 probability level.

In order to determine which of the four means for RT_2 in the SRC conditions were significantly different, a Neuman-Keuls test was performed (Appendix B). The results led to the conclusion that all conditions were significantly different at the .01 probability level. The overall mean values for the four conditions were: (SS) 187 milliseconds, (SC) 225 milliseconds, (CS) 317 milliseconds, and (CC) 357 milliseconds. Hypothesis 1, which stated that reaction time to a stimulus signaling the amendment of a complex motor plan and the initiation of a simple one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one, was thus supported. In addition, as a result of the differing means between SC and SS, Hypothesis 2, which stated that the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a complex one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one, was also supported. It is also interesting to note that CS was longer than SC; this suggests that recovery from the past response appears to be a more important determiner of RT_2 than is the planning of the next response.

The percentage of total variance in RT_2 accounted for by SRC was calculated via Omega Square and found to be 57%. Figure 5 on page 61 illustrates the SRC effect and the separation of fast and slow speed groups on both RT_1 and RT_2.[a]

Interstimulus Interval

The data from Table 5 only partially supported Hypothesis 3, which stated that reaction time to a stimulus signaling the amendment of one motor plan and the initiation of another one, increases as the ISI decreases from 400 milliseconds to 200 milliseconds, and from 200 milliseconds to 100 milliseconds. Although the ISI factor resulted in an F value of 22.2129, which for 3 and 66 df was significant beyond the .01 probability level, the Neuman-Keuls post-hoc test revealed differences only between the mean for the 100 milliseconds ISI, which was 294 milliseconds, and those for ISIs of 200, 400, and 800 milliseconds, which were respectively 261, 268, and 262 milliseconds.

---

[a]The graph is intended to illustrate the effects. It is acknowledged that the conditions illustrated are discrete.

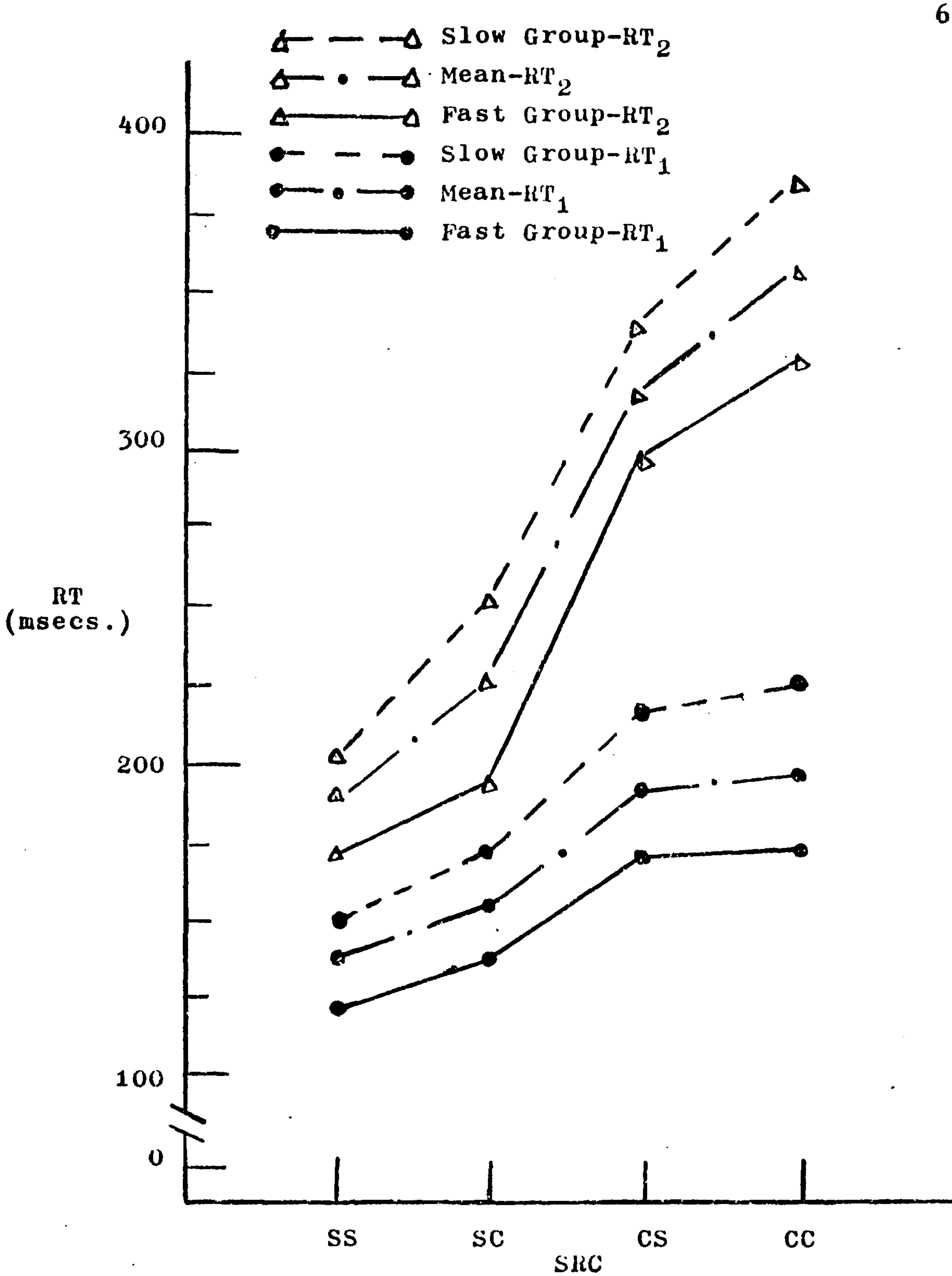


Figure 5. Graphic illustration of the SRC effect and the separation of fast and slow speed groups on both RT_1 and RT_2.

The percentage of variance in RT_2 accounted for by the factor of ISI was found to be 2%. Figure 6 on page 63 graphically respresents the effect of ISI on RT_1 and RT_2.

Speed Classification

Table 5 reveals that fast and slow speed groups, based on the composite reaction time measures from Day 2, remained fast and slow as groups on RT_2. This finding was supported by the *F* value for the factor of speed, which was 11.77785. For 1 and 22 *df* this statistic was significant at the .01 probability level. Since speed did not interact with any other factors, it can be deduced that the two groups maintained their relative positions within all conditions. The overall mean values for the fast and slow groups were respectively 250 and 292 milliseconds. These data, in contrast to Hypothesis 4, indicate that a difference does exist in reaction time to a stimulus signaling the amendment of one response and the initiation of another one between those individuals grouped as fast and slow responders in a single, simple reaction time task situation. Omega Square was calculated for the factor of speed and found to account for 5% of the total variance in RT_2. Figures 5, 6, and 7, which respectively illustrate the main effects of SRC, ISI, and days, also include illustrations pertaining to fast and slow groups across these conditions.

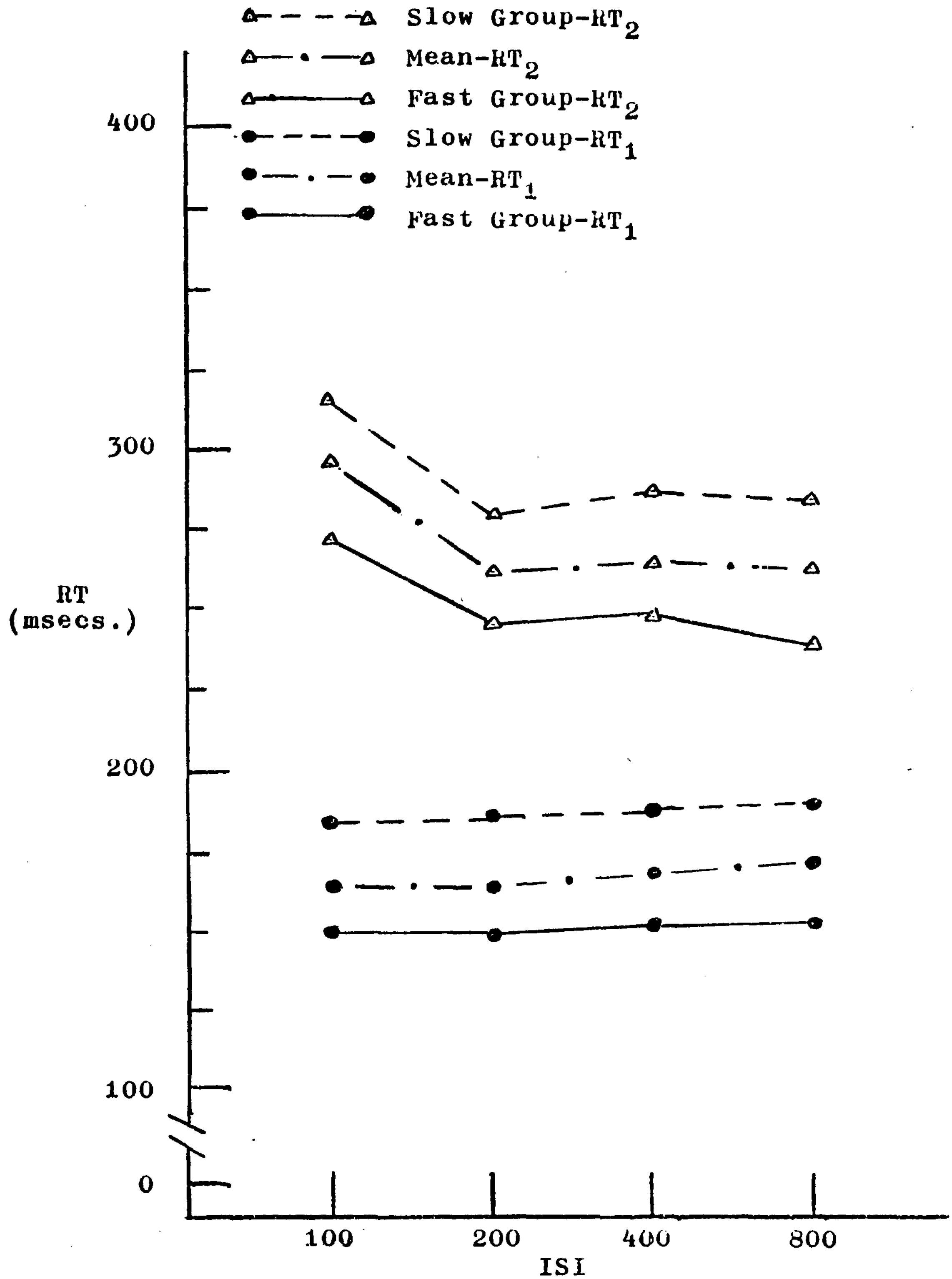


Figure 6. Graphic illustration of the ISI effect and the separation of fast and slow speed groups on both RT_1 and RT_2.

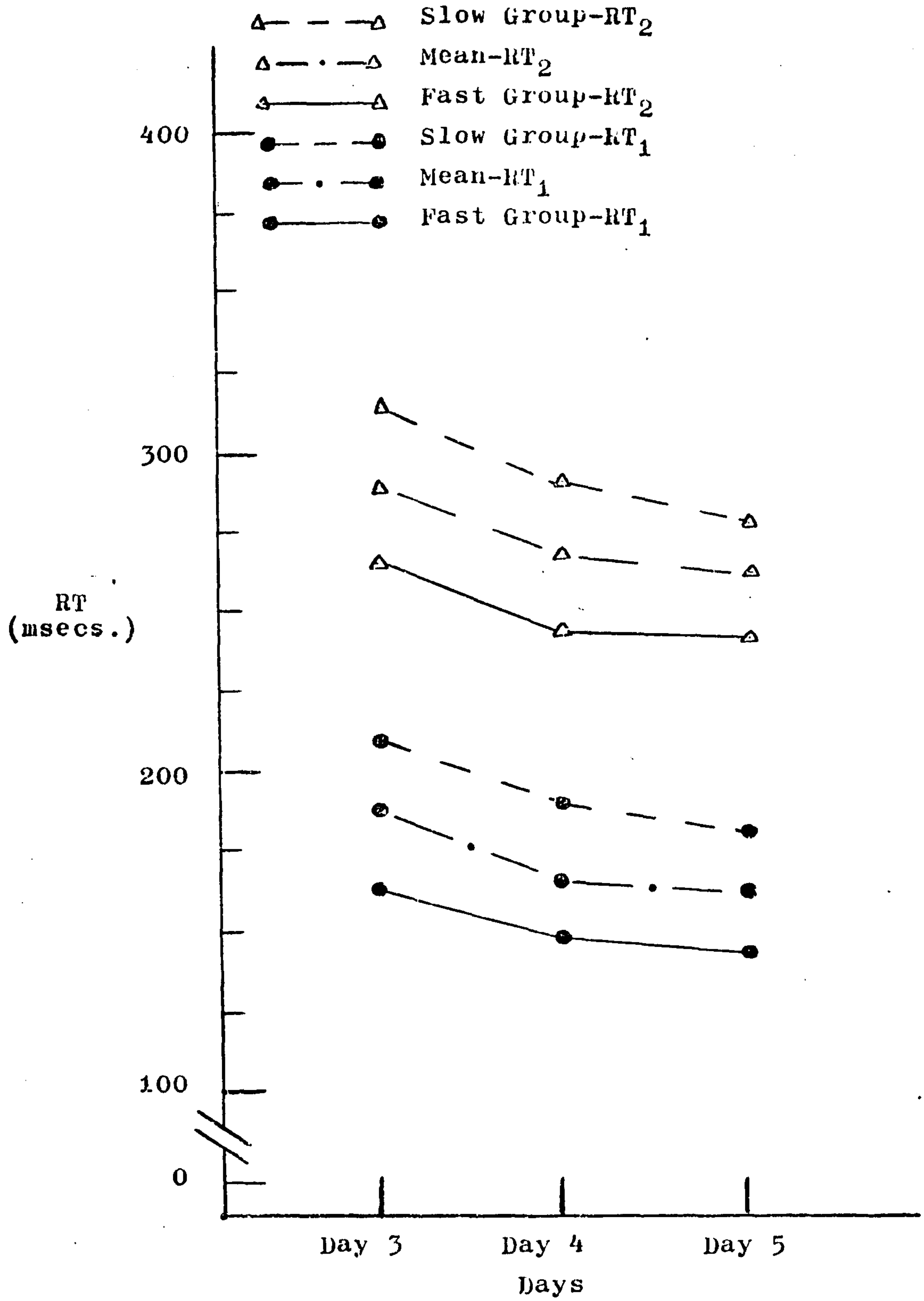


Figure 7. Graphic illustration of the day effect and the separation of fast and slow speed groups on both RT_1 and RT_2.

Day Effect

Since each of the last three sessions was run on different days, this effect was examined via the analysis of variance. An *F* value of 22.2129 was found for this factor which, for 2 and 44 *df*, is significant at the .01 probability level. The Neuman-Keuls test was performed on the overall means for Days 3, 4, and 5, which were respectively 286, 268, and 260 milliseconds. The mean of Day 3 was found to be significantly slower than the mean of Day 4 at the .01 level, while the mean of Day 4 was found to be significantly slower than the mean of Day 5, at the .05 level. This finding suggested that learning had taken place on each of the last three days. However, the percentage of variance in RT_2 accounted for by this factor was only 1%. Figure 7, on page 64, graphs the day effect on RT_1 and RT_2 for fast and slow groups.

Interaction of SRC and ISI

The analysis of variance revealed a significant interaction between the factors of SRC and ISI. The *F* value for this effect was 19.6995 which, for 9 and 198 *df*, was significant at the .01 probability level. This interaction indicated that all conditions of SRC did not follow a similar pattern over the ISIs. Figure 8, on page 66, illustrates that the form of the curves in the SS and SC conditions

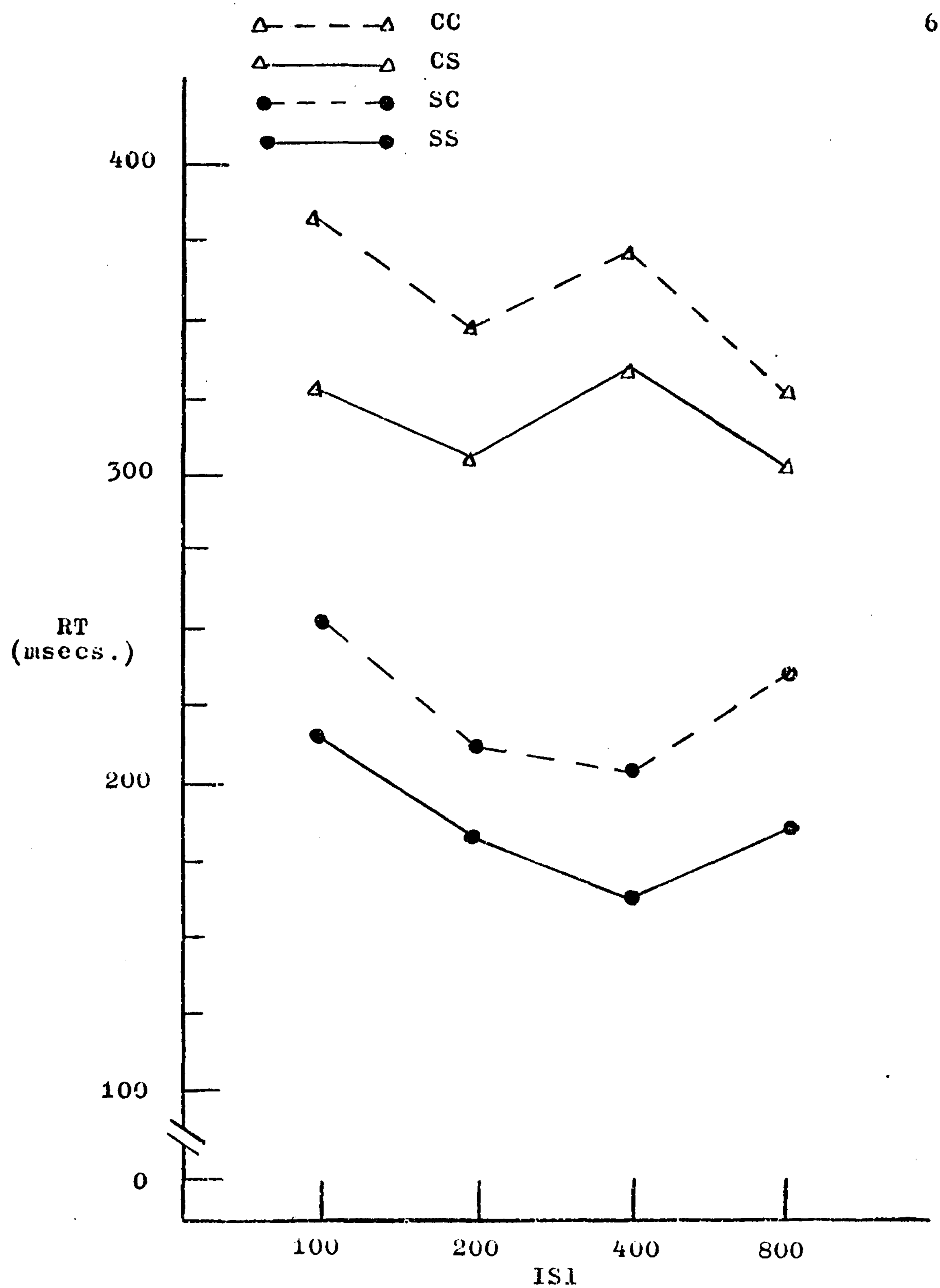


Figure 8. Graphic illustration of ISI-SRC interaction.

were similar, as were those in the CS and CC conditions. However, the latter pair, in which the complex condition occurred first, appeared to differ from the former pair, in which the simple response was first. The CS and CC conditions showed a decrease in RT_2 when S_2 occurred at 200 milliseconds, as compared when it occurred at 100 milliseconds, but when S_2 occurred at 400 milliseconds, RT_2 showed an inversion and reverted back to its ISI of 100 milliseconds level. In contrast, SRC conditions SC and SS appeared to show a declining RT_2 with increasing ISI, until the 800 milliseconds interval, at which time RT_2 increased. The Neuman-Keuls test for the simple effects of the SRC-ISI interaction revealed the following: (a) for the SRC of SS, RT_2 decreased progressively from the ISI of 100 milliseconds to the ISI of 200 milliseconds, and from the ISI of 200 milliseconds to the ISI of 400 milliseconds, but increased at the 800 milliseconds ISI to become longer than the 400 milliseconds ISI, and comparable to that RT_2 at the 200 milliseconds ISI, (b) for the SRC of SC, RT_2 was longest for the 100 milliseconds ISI, equivalent for the 200 and 400 milliseconds ISIs, and longer for the 800 milliseconds ISI than the 200 or 400 milliseconds ISI, (c) for CS, RT_2 was equivalent at the 100 and 400 milliseconds ISIs, and 200 and 800 milliseconds

ISIs, but the former pair had RT_2s which were both longer than those of the latter pair, and (d) for the CC SRC, RT_2 was equivalent at the 100 and 400 milliseconds ISIs, and progressively shorter at the 200 and 800 milliseconds ISIs. Additionally, Figure 8, on page 66, graphically illustrates the effect of each interval on RT_2 for each SRC condition. On the other hand, Figure 9, on page 69, demonstrates the effect of SRC conditions on RT_2 at each ISI level.

From both figures and the Neuman-Keuls tests, it was clearly evident that the effect of SRC was a much more influential determiner of RT_2 than was ISI. The percentage of variance in RT_2 accounted for by the SRC-ISI interaction was found to be 2%.

<u>Interaction of Days with ISI</u>

Over the three days in which data were generated, the patterns of decreasing RT_2 at each ISI were different. As illustrated in Figure 10, on page 70, and supported by a Neuman-Keuls test, the largest decrease in RT_2 occurred at the 800 milliseconds ISI. Significant decreases in RT_2 took place at this interval, from Day 3 to Day 4 and from Day 4 to Day 5. However, RT_2 at other ISIs showed less dramatic decreases. At the 100 and 200 milliseconds intervals, RT_2 decreased from Day 3 to Day 4, but Day 5 values

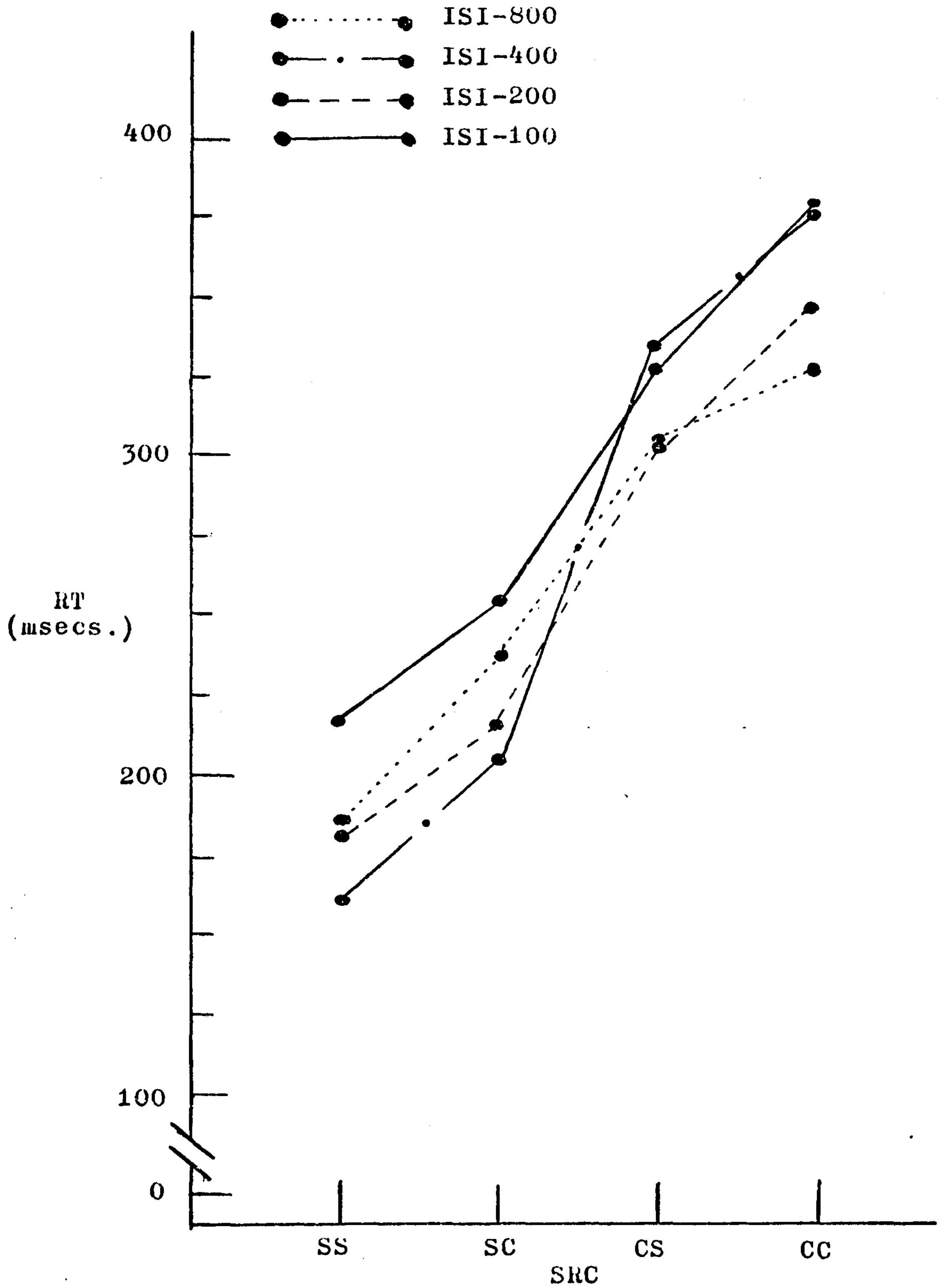


Figure 9. Graphic illustration of the effect of SRC conditions on RT_2 at each ISI level.

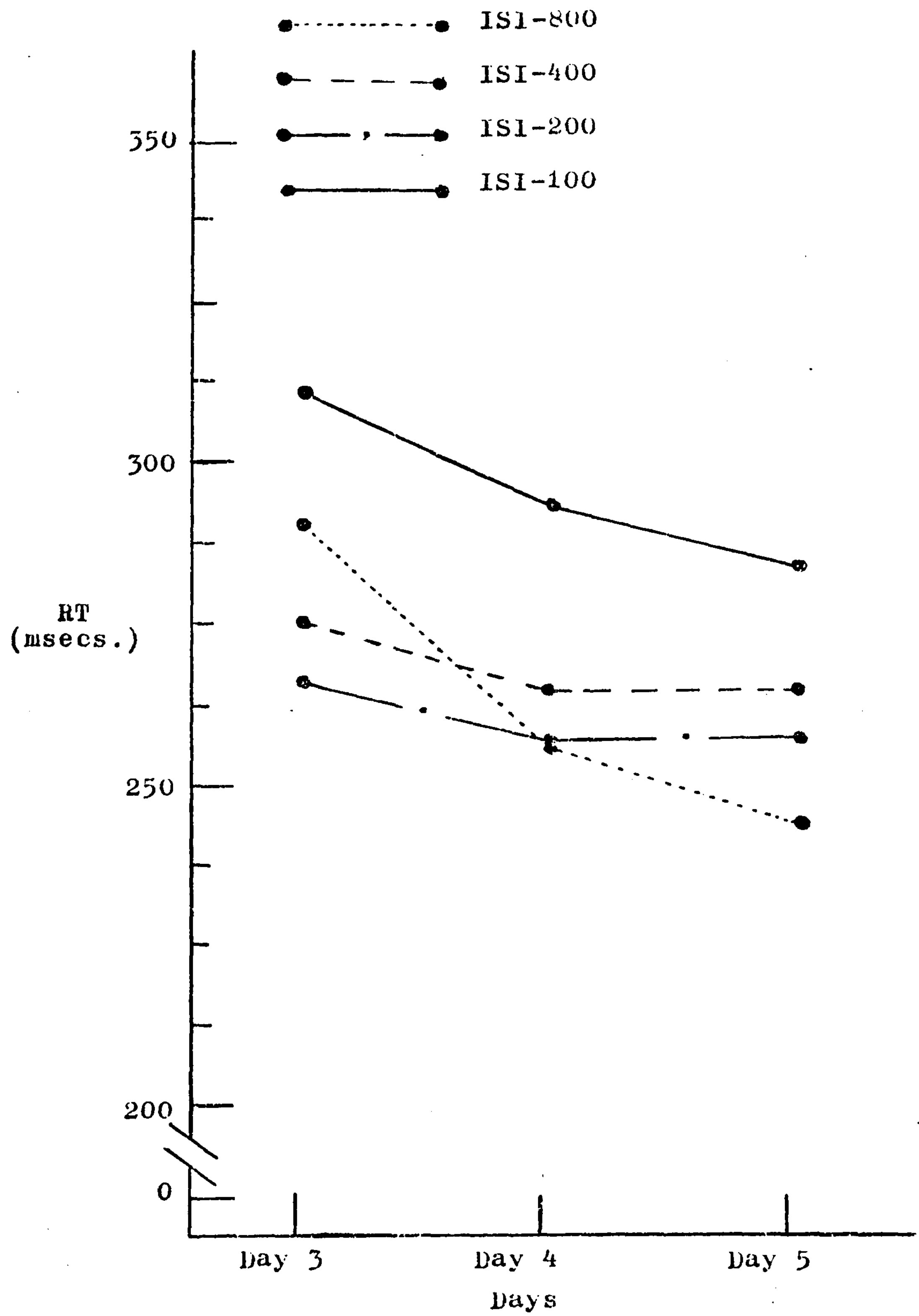


Figure 10. Graphic illustration of RT_2 times at each ISI over days.

were equivalent to those of Day 4. RT_2 at the 400 milliseconds ISI remained statistically equivalent over all the days, although it seemed to have a decreasing trend from Day 3 to Day 4.

Figure 11, on page 72, illustrates daily times for RT_2 at each ISI. The Neuman-Keuls post-hoc test revealed the following: (a) for Day 3, RT_2 decreased from the 100 milliseconds ISI to the 200 and 400 milliseconds ISIs, where it was equivalent, and then it increased at the 800 milliseconds ISI, (b) for Day 4, RT_2 decreased from the 100 milliseconds ISI to the 200, 400, and 800 milliseconds ISIs, where it was equivalent, and (c) for Day 5, RT_2 decreased from the 100 milliseconds ISI to the 200 and 400 milliseconds ISIs, where it was equivalent, and then decreased at the 800 milliseconds ISI. Thus, it seemed that the dramatic decrease in RT_2 at the 800 milliseconds ISI, over the three day period, was primarily responsible for the ISI-days interaction. This was anticipated, since subjects probably learned to perform the complex response task, each day, with less extraneous movement, and thus, by Day 5, were entirely through with it when S_2 occurred. However, when Omega Square was calculated for this interaction effect, it was found to account for only .5% of the variance of RT_2 in the entire experiment.

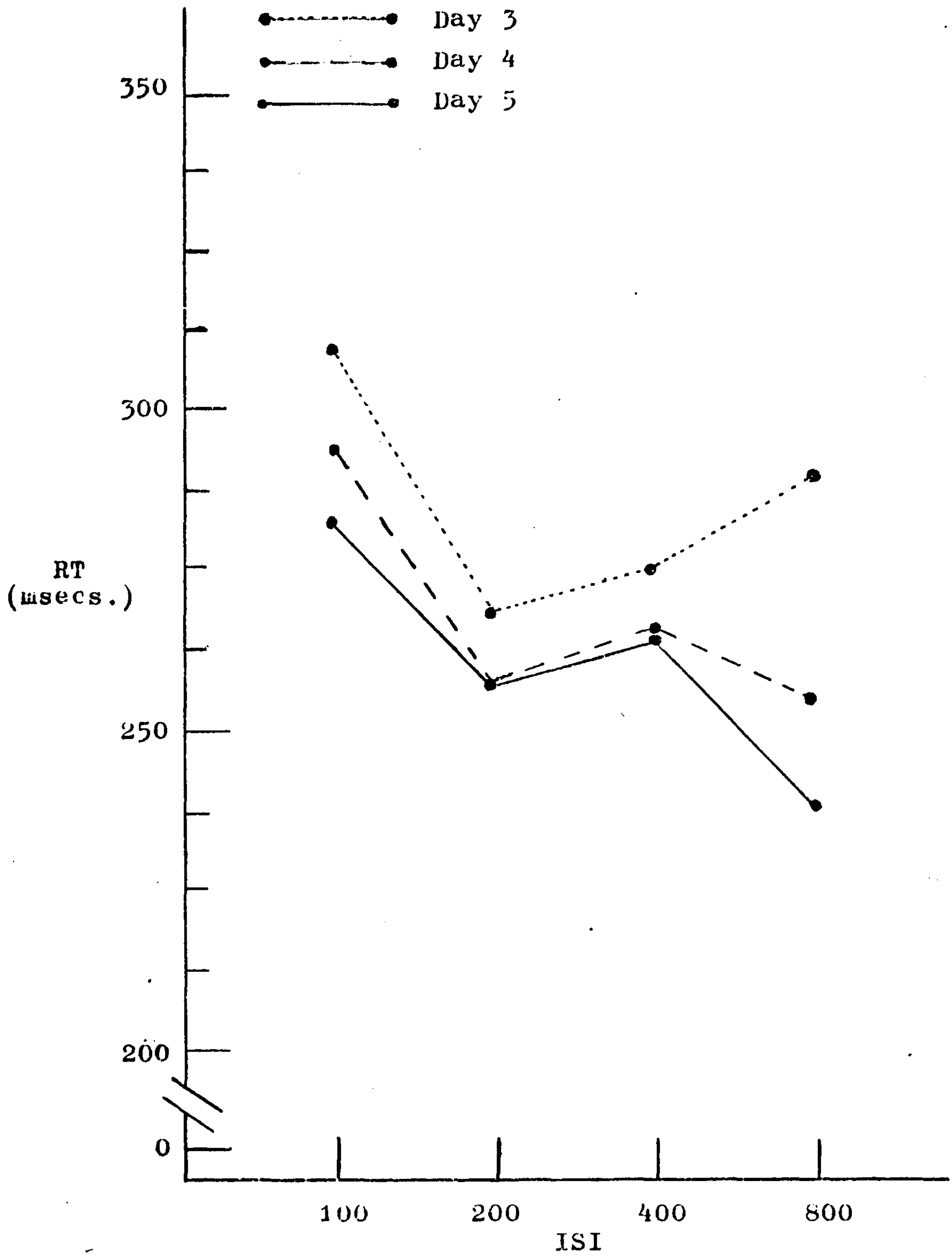


Figure 11. Graphic illustration showing differing RT_2 patterns across ISIs on each day.

Interaction of Days and SRC

Figure 12, on page 74, illustrates the days-SRC interaction. The graph and Neuman-Keuls test indicate that the CC condition showed the greatest decrease in RT_2 over all three days. For this condition, Day 4 was faster than Day 3, and Day 5 faster than Day 4. Conditions SS and SC showed decreasing RT_2s only between Day 3 and Day 4, while condition CS showed no improvement at all. The percentage of variance of RT_2 accounted for by this interaction was .5%.

Interaction of Days, SRC, and ISI

The final significant finding from this experiment was the triple interaction among days, SRC, and ISI. Figures 13, 14, and 15, on pages 75 and 76, illustrate the changing pattern of the CS condition as RT_2 decreases at the 800 milliseconds ISI from Day 3 to Day 4. Figures 14 and 15 show that the patterns of all conditions on Days 4 and 5 are similar to those represented by the SRC-ISI interaction in Figure 8, on page 66. This suggested that the interaction among these factors was primarily a result of the decrease in RT_2, in the CS condition at the 800 milliseconds ISI, between Days 3 and 4. The percentage of variance of RT_2 accounted for by this effect was .5%.

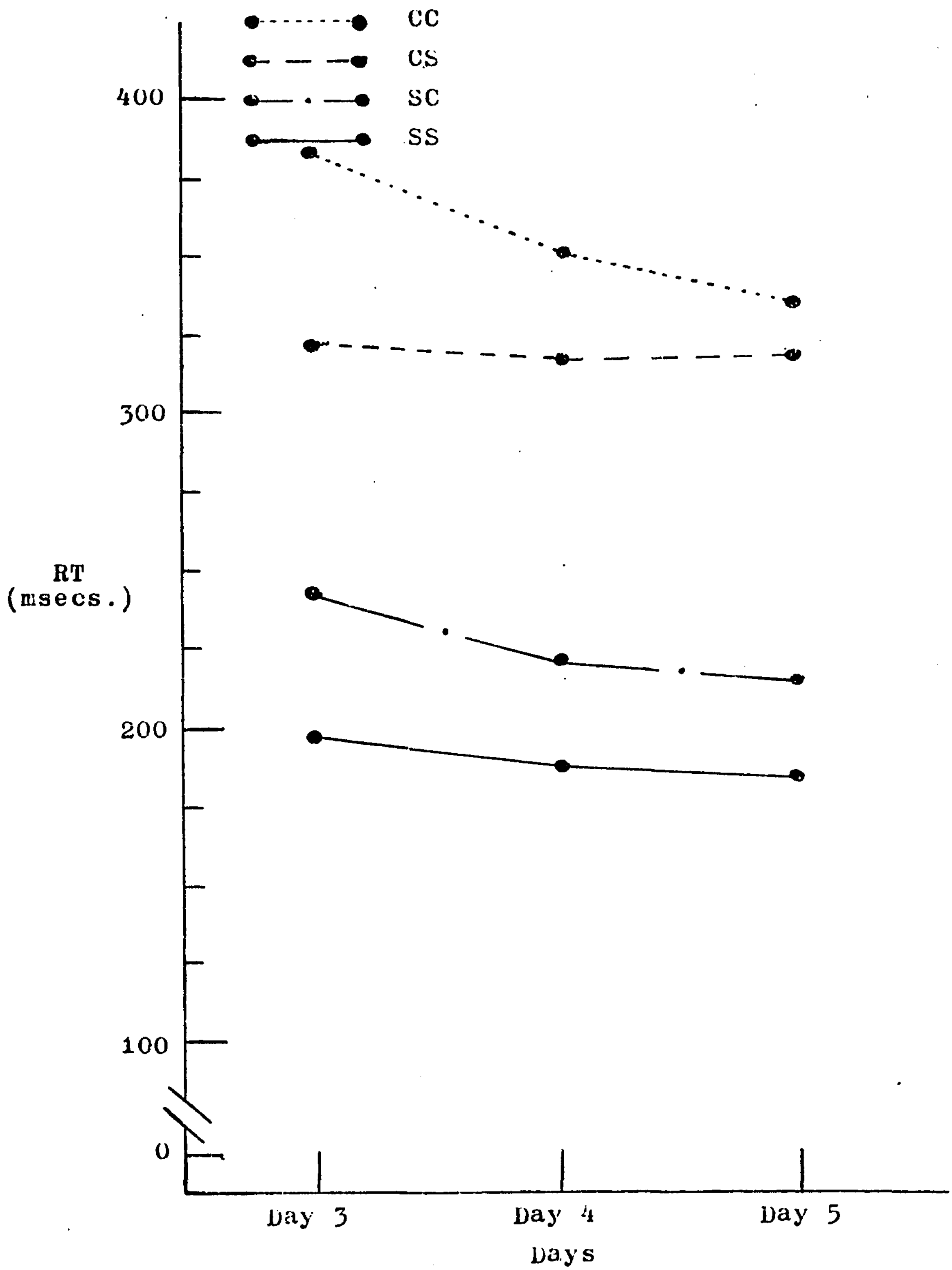


Figure 12. Graphic illustration of the SRC-days interaction.

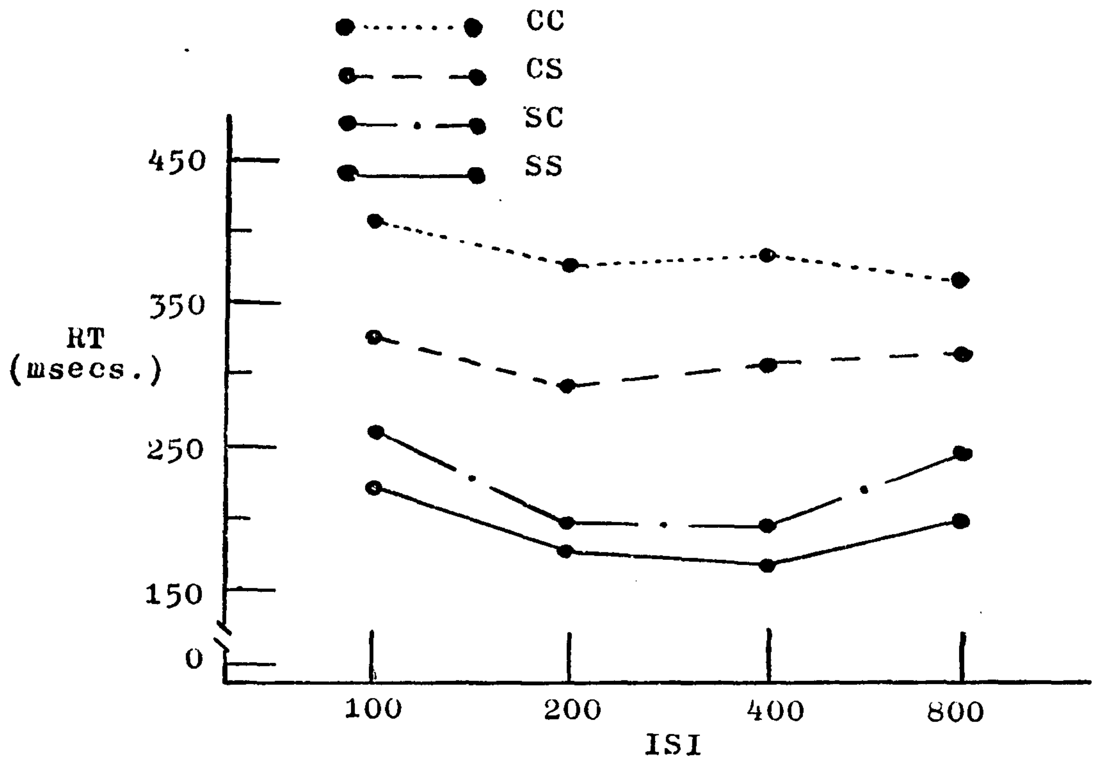


Figure 13. Graphic illustration of SRC-ISI interaction at Day 3.

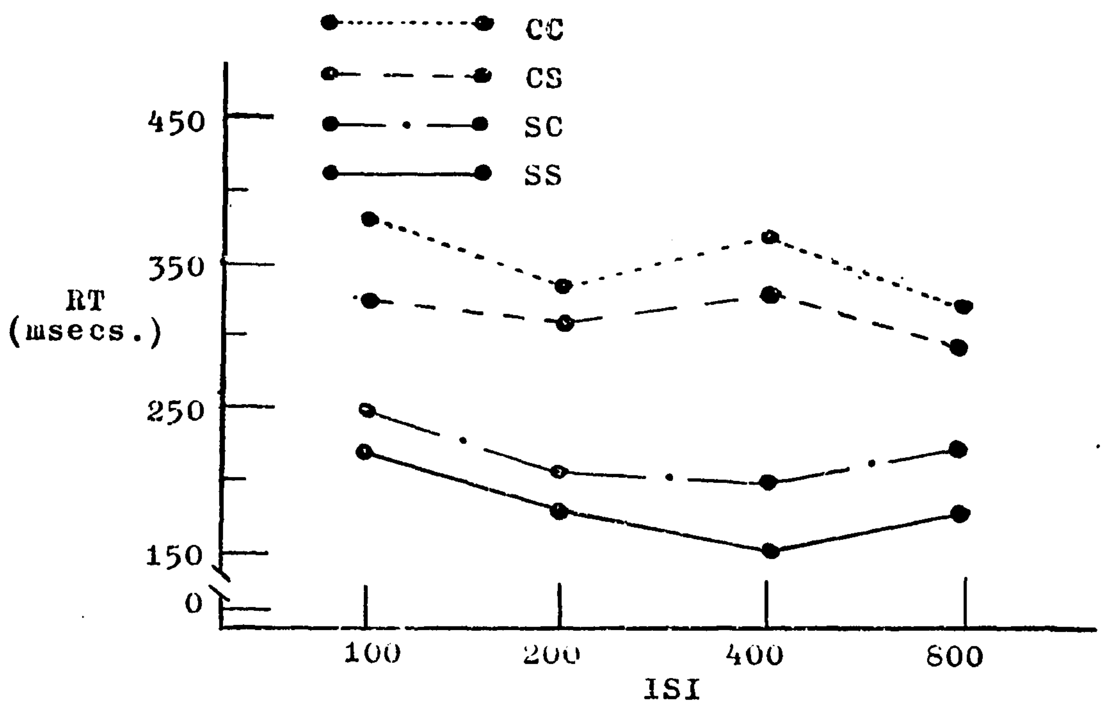


Figure 14. Graphic illustration of SRC-ISI interaction at Day 4.

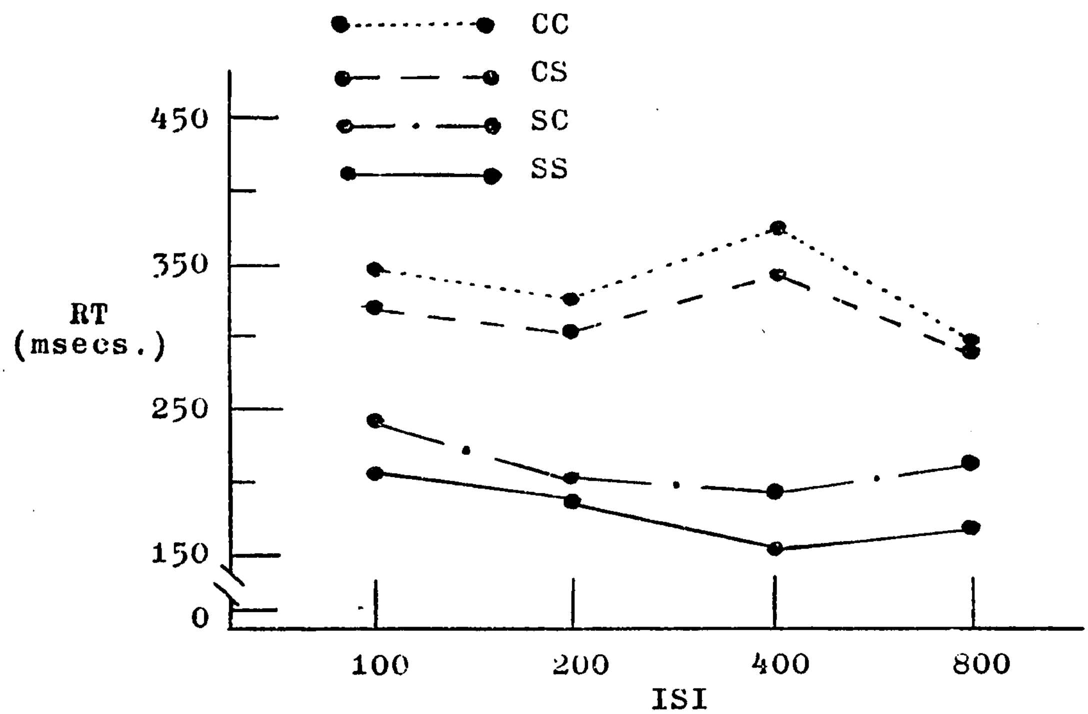


Figure 15. Graphic illustration of SRC-ISI interaction at Day 5.

Variance Accounted For

Table 6 provides the collated Omega Square values for all significant sources of variation in the experiment. Obtained values indicate that SRC was unquestionably the most important factor in determining RT_2 because it accounted for 57% of its observed variance. When all orthogonal effects in the experiment were considered cumulatively, experimental factors accounted for 68.4% of the total variation in RT_2.

Table 6

Experimental Variance

Source	Omega Square
C	57.0%
A	5.0%
I	2.0%
CI	2.0%
D	1.0%
DI	.5%
DCI	.5%
DC	.4%
Total	68.4%

Note. C=SRC, A=speed, I=ISI, D=days.

Discussion

The results of this study were in accord with the deductions generated from Henry's (1960) "memory drum" theory of neuromotor reactions. The time taken to amend one response and implement another one was increased when the initial movement task was complex. In addition, given similar responses for the first task, RT_2 was longer when the second response required the more complex movement. When the effects of both successive responses were compared in terms of their relative influence on RT_2, it appeared that amending the first movement was more important than preparing for and initiating the subsequent movement.

In addition to supporting the deductions from Henry's theory, the pattern of delays in RT_2 resulting from the SRC-ISI interaction seem to offer some insight into the underlying processes involved in initiating and amending neuromotor programs. For example, excluding the 800 milliseconds interval, the SC and SS conditions appeared to follow a trend of decreasing RT_2s with increasing ISIs, while the CS and CC conditions showed an inversion in this pattern at the 400 milliseconds interval. A possible explanation for this disparity in trends may be offered in terms of the number of processes required in each pair of conditions prior to the initiation of the second movement. When S_2 occurred at the 400 milliseconds ISI, subjects in those tasks having an initial simple response could immediately begin to organize and implement the successive movement since the first one had been completed. However, when S_2 signaled at the 400 milliseconds ISI, for those tasks having a complex initial response, movement was still ongoing, and probably only about a third of the way finished. Thus, in addition to having to organize and implement a subsequent program, an inhibitory response had to first be prepared to arrest the ongoing one. Hence, RT_2 was incremented by this additional processing time, which amounted to about an average of 170 milliseconds between pairs of conditions.

By similar reasoning, an explanation for the inflated RT_2s at the 400 milliseconds ISI, in contrast to the 200 milliseconds ISI within tasks with an initial complex response, may be suggested. However, in such a comparison of RT_2s at these ISIs, the number of processes between the signaling of S_2 and the initiation of the successive response would not seem to differ in that, at both intervals, an inhibitory program would be required to stop the first response. Rather, the quality of each program is at issue. Considering that the initial reaction times for the CC and CS conditions were 198 and 194 milliseconds respectively, while the total movement time was approximately 552 milliseconds (Henry, 1960), when S_2 occurred at the 400 milliseconds interval, the overt response would have already been ongoing for between 202 and 206 milliseconds. It seems likely that by this time, subjects would have already struck the first tennis ball with the back of their hand and begun the series of linear movements and reversals necessary to complete the task. However, the occurence of S_2 signaled subjects to arrest their initial response as quickly as possible, and begin the next one. According to Hick (1948) this would require the nervous system to assess the present limb position, determine its direction, and project its future pattern so that the appropriate response units, i.e., simple movements, effected by a muscle, or group of muscles, represented centrally in the brain (Glencross, 1973), may be selected, temporally organized, and subsequently initiated as a motor program that will activate the proper antagonists. Considering that a reaction time would be required for this assessment and programming, the limb would have continued to move through the originally planned response, and begun to enter its final stages when the inhibitory program was implemented. In the complex movement this entailed grasping the ball and pulling it down. In relation to the rest of the task this action would seem to require the finest control, in that spatial and temporal demands for grasping would appear to be more stringent than for the grosser movements of swinging the arm through the specified pattern. Hence, the inhibitory motor program for arresting movement at its point of greatest complexity was probably reflected by the increased RT_2s at the 400 milliseconds ISI. In comparison, the amending program for S_2 at the 200 milliseconds ISI would have been relatively uninvolved. At this point in the initial complex response, subjects could have only been starting their response. Since the initiation of an inhibitory program would have occurred a reaction time later, it probably was organized to amend a linear movement or change of direction in the ongoing response. Glencross' (1972;1973) results indicated that neither of these response characteristics greatly affect response latency, and thus it may be presumed that the assembling, organizing, and implementing of an inhibitory program was relatively expeditious, and thus, reflected by the shorter RT_2s at the 200 milliseconds ISI.

The import of this analysis of amending ongoing responses would seem to be significant in that not only are complexity differences recognized between programmed movements, but also within them. Henry (1960) recognized that the position of complexity within a programmed response might have a bearing on its associated response latency. The present study seems inadvertently to support such a contention. Hence, it would seem that simple reaction time, as a criterion for the complexity level of a programmed movement, may not reflect the complexity of the entire response, but rather the placement of the most highly organized response units.

Finally, the finding that individuals grouped into different categories of speed, based on single measures of reaction time generated during Day 1 and Day 2, maintained their relative positions across all SRCs, all ISIs, and on all days when RT_2s were compared was diametrically opposed to Kroll's (1969) results. Subsequent inspection of initial paired reaction times for each group resulted in a similar finding. In contrast to Kroll's conclusions, this would seem to indicate a general speed factor in making fast, consecutive responses. A possible, although not probable, explanation for this discrepancy in results may be offered in terms of learning. Kroll allowed four days of practice in the single situation, and six days in the dual one. Additionally, SRC was not a factor in his study, thus, each subject had more practice time on the SS SRC, which was used exclusively. The overall trend in the present study was for the two groups to merge from Day 3 to Day 5. However, even at Day 5 the two groups differed substantially. Subsequent research investigating the differing RT_2 patterns between fast and slow groups over an extended time period would seem to be needed to adequately resolve these conflicting conclusions.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This investigation examined the effects of the sequence of response complexity (SRC), interstimulus interval (ISI), and the subject speed classification based on reaction time in a single response situation, on the variation in reaction time to the second of two successive responses. The following hypotheses were posed for this study:

Hypothesis 1. The reaction time to a stimulus signaling the amendment of a complex motor plan and the initiation of a simple one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

Hypothesis 2. The reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a complex one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

Hypothesis 3. The reaction time to a stimulus signaling the amendment of one motor plan and the initiation of another one increases as the ISI decreases from 400 milliseconds to 200 milliseconds, and from 200 milliseconds to 100 milliseconds.

Hypothesis 4. No difference exists in reaction time to a stimulus signaling the amendment of one response and initiation of another one between those individuals grouped as fast and slow responders in a single, simple reaction time task.

Procedures

Measures of reaction time on single and sequential response tasks were generated from 24, female, right-handed volunteers from the University of North Carolina at Greensboro during the fall semester of 1974. Subjects were required to attend sessions on five different days.

During Day 1 and Day 2, each subject was administered 50 simple, and 50 complex response reaction time trials with each hand. The simple response consisted of lifting an index finger off of a reaction time key. The complex response required a series of linear movements and reversals. Both were initiated by the sound of a stimulus buzzer, and performed as quickly as possible.

On Days 3 to 5 each subject was asked to perform four different blocks of trials having different sequences of response complexity utilizing the tasks practiced on the first two days. The sequences included: (a) executing a simple response following a simple response (SS), (b) executing a complex response following a simple response (SC), (c) executing a simple response following a complex response (CS), and (d) executing a complex response following a complex response (CC).

Data for Days 1 and 2 consisted of mean reaction times for each subject, on each task, for each day. Data for Days 3 to 5 were similarly composed of means for each subject, on each day, for the initial and successive responses in each of the four different tasks.

Findings

A multivariate analysis of variance was performed on right-handed, simple and complex response reaction times for all subjects over the first two days. A significant *F* ratio was found indicating that Day 2 scores were significantly faster than Day 1 scores. Complex response reaction time was also found to be a better discriminator between day times, than was simple response reaction time.

On the basis of Day 2 scores for complex response reaction time, the 24 subjects were divided into two groups of 12, with one being relatively fast on this variable in relation to the other.

A discriminant analysis was then calculated using both simple and complex response reaction times of Day 2 as group predictor variables. The findings, based on the generalized squared distance to each group's mean composite variable, resulted in all subjects having been classified correctly.

An analysis of variance for repeated measures was performed to test the effects of SRC, ISI, speed classification, and days on RT_2. The analysis revealed that SRC was the most important determiner of RT_2. Post-hoc tests among means for each SRC level, across all conditions, showed that RT_2 was significantly longer when the complex response was first in the sequence. Similarly, RT_2 reflected the complexity level of the second response, but to a lesser degree. Based on these findings, Hypotheses 1 and 2 were accepted.

The factor of ISI accounted for only 2% of the explained variance in RT_2. In addition, post-hoc tests revealed that when ISI was considered in relation to RT_2, times were elongated only at the 100 milliseconds interval. On this basis, Hypothesis 3 was rejected.

Classification of subjects into fast and slow groups helped to explain 5% of the variance of RT_2. Each group was found to remain intact across all experimental conditions; thus Hypothesis 4 was rejected.

In addition, a significant interaction was found to exist between the factors of ISI and SRC. This was unanticipated, but indicated that the effect of SRC determines to a large extent the effect that ISI will have on RT_2.

Finally, the day effect, the day-SRC interaction, the day-ISI interaction, and the day-SRC-ISI interaction, all indicated that RT_2 decreased as the experiment progressed from Day 3 to Day 5, with greatest improvement occurring between Day 3 and Day 4.

Conclusions

Within the limitations of this study, the following conclusions seem justified:

1. The reaction time to a stimulus signaling the amendment of a complex motor plan and the initiation of a simple one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

2. The reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a complex one is longer than the reaction time to a stimulus signaling the amendment of a simple motor plan and the initiation of a simple one.

3. The sequence of response complexity was more important in determining RT_2 than was the interstimulus interval.

4. The initial response determined RT_2 to a greater extent than the successive one.

5. The reaction time to a stimulus signaling the amendment of one motor plan and the initiation of another one decreases from an ISI of 100 milliseconds to an ISI of 200 milliseconds.

6. Individuals classified as fast and slow responders in a single, simple reaction time task situation remain fast and slow in reaction time to a stimulus signaling the amendment of one response and the initiation of another one over a sequence of trials and days.

7. Reaction time in a single task situation, and in one requiring fast, consecutive responses to closely paired stimuli, decreases with practice.

Recommendations

The present investigation led to the following recommendations for future study:

1. Measure the time interval between deceleration of the first response and initiation of the second one in order to quantify the relative importance of each as determiners of RT_2.

2. Divide subjects into fast and slow responders based on reaction time in a single task situation, and examine each group's decreasing RT_2s over an extended period.

3. Study the effect of response selection on RT_2 by changing the experimental set-up so that each of the two responses must be selected from a pool of other possible ones.

4. Using three successive responses, each initiated by a separate stimulus event, determine the relative magnitudes of RT_1, RT_2 and RT_3.

5. Determine the spatial position of the limb performing the initial response at the time S_2 occurs through the use of a photographic method.

6. Replicate this study controlling for the degree of hand dominance in addition to hand preference.

BIBLIOGRAPHY

Adams, J. A. Test of the hypothesis of psychological refractory period. Journal of Experimental Psychology, 1962, 64, 280-287.

Adams, J. A. Motor skills. Annual Review of Psychology, 1964, 15, 181-202.

Bertelson, P. Central intermittency twenty years later. Quarterly Journal of Experimental Psychology, 1966, 18, 153-163.

Boddy, J. The psychological refractory period and vertex evoked potentials. Quarterly Journal of Experimental Psychology, 1972, 24, 175-192.

Botwinick, J. and Thompson, L. N. Premotor and motor components of reaction time. Journal of Experimental Psychology, 1966, 71, 9-15.

Brown, J. S. and Slater-Hammel, A. T. Discrete movements in the horizontal plane as a function of their length and direction. Journal of Experimental Psychology, 1949, 39, 84-95.

Craik, K. J. W. Theory of the human operator in control systems. I. The operator as an engineering system. British Journal of Psychology, 1947, 38, 56-61.

Craik, K. J. W. Theory of the human operator in control systems. II. Man as an element in a control system. British Journal of Psychology, 1948, 38, 142-148.

Creamer, L. R. Event uncertainty, psychological refractory period, and human data processing. Journal of Experimental Psychology, 1963, 66, 187-194.

Davis, R. The limits of the "psychological refractory period." Quarterly Journal of Experimental Psychology, 1956, 8, 24-38.

Davis, R. The human operator as a single-channel information system. Quarterly Journal of Experimental Psychology, 1957, 9, 119-129.

Davis, R. The role of "attention" in the psychological refractory period. Quarterly Journal of Experimental Psychology, 1959, 11, 211-220.

Davis, R. Choice reaction times and the theory of intermittency in human performance. Quarterly Journal of Experimental Psychology, 1962, 14, 157-166.

Davis, R. Expectancy and intermittency. Quarterly Journal of Experimental Psychology, 1965, 17, 75-78.

Dixon, W. J. Biomedical computer programs. Berkeley: University of California Press, 1973.

Elithorn, A. and Lawrence, C. Central inhibition--some refractory observations. Quarterly Journal of Experimental Psychology, 1955, 7, 116-127.

Fitts, P. M. and Peterson, J. R. Information capacity of discrete motor responses. Journal of Experimental Psychology, 1964, 67, 103-112.

Freeman, F. N. Preliminary experiments on writing reactions. Psychological Monographs, 1907, 8, 301-333.

Glencross, D. J. Latency and response complexity. Journal of Motor Behavior, 1972, 4, 251-256.

Glencross, D. J. Response complexity and the latency of different movement patterns. Journal of Motor Behavior, 1973, 5, 95-104.

Harrison, J. S. Psychological refractoriness and the latency of two consecutive motor responses. Research Quarterly, 1960, 31, 590-600.

Hays, W. L. Statistics. New York: Holt, Rinehart, and Winston, 1963.

Henry, F. M. Increased response latency for complicated movements and a "memory drum" theory of neuromotor reaction. Research Quarterly, 1960, 31, 448-458.

Henry, F. M. and Harrison, J. S. Refractoriness of a fast movement. Perceptual and Motor Skills, 1961, 13, 351-354.

Hick, W. E. Discontinuous functioning of the human operator in pursuit tasks. Quarterly Journal of Experimental Psychology, 1948, 1, 36-37.

Howell, M. L. Influence of emotional tension on speed of reaction and movement. Research Quarterly, 1953, 24, 22-32.

Kroll, W. Quality of simple reaction time and the psychological refractory period. Research Quarterly, 1969, 40, 105-114.

Kay, H. and Weiss, A. D. Relationship between simple and serial reaction time. Nature, 1961, 191, 790-791.

Mowrer, D. H. Preparatory set (expectancy) some methods of measurement. Psychological Monographs, 1940, 52, (2, Whole No. 233).

Newell, K. and Martens, R. Applications of multivariate analysis of variance in motor behavior research. In M. G. Wade and R. Martens (Eds.), Psychology of motor behavior and sport. Urbana: Human Kinetics Publishers, 1974.

Nickerson, R. S. Response time to the second of two successive signals as a function of the absolute and relative duration of intersignal interval. Perceptual and Motor Skills, 1965, 21, 3-10.

Norrie, M. Effects of movement complexity on choice reaction and movement times. Research Quarterly, 1974, 45, 154-161.

Pacaud, S. Contribution a l'etude des movements volontaires. Annals of Psychology, 1942, 40, 152-170.

Poulton, E. C. Perceptual anticipation and reaction time. Quarterly Journal of Experimental Psychology, 1950, 2, 99-113.

Rao, C. R. Linear statistical inferences and its applications. New York: John Wiley and Sons, Inc., 1965.

Schmidt, R. A. and Stull, G. A. Premotor and motor reaction time as a function of preliminary muscular tension. Journal of Motor Behavior, 1970, 11, 96-110.

Searle, L. V. and Taylor, F. V. Studies of tracking behavior. I. Rate and time characteristics of simple movements. *Journal of Experimental Psychology*, 1948, 38, 615-631.

Service, J. *A user's guide to the statistical analysis system*. Raleigh: Sparks Press, 1972.

Slater-Hammel, A. T. Psychological refractory period in simple paired responses. *Research Quarterly*, 1958, 29, 468-481.

Smith, M. C. Theories of the psychological refractory period. *Psychological Bulletin*, 1967, 67, 202-213.

Telford, C. W. Refractory phase of voluntary and associative responses. *Journal of Experimental Psychology*, 1931, 14, 1-35.

Vince, M. A. Intermittency of control movements and the psychological refractory period. *British Journal of Psychology*, 1947, 38, 149-157.

Vince, M. A. and Welford, A. T. Time taken to change the speed of a response. *Nature*, 1967, 213, 532-533.

Weiss, A. D. The locus of reaction time change with set, motivation, and age. *Journal of Gerontology*, 1965, 20, 60-64.

Welford, A. T. The "psychological refractory period" and the timing of high-speed performance: a review and a theory. *British Journal of Psychology*, 1952, 43, 2-19.

Welford, A. T. Evidence of a single-channel decision mechanism limiting performance in a serial reaction task. *Quarterly Journal of Experimental Psychology*, 1959, 11, 193-210.

Welford, A. T. Single-channel operation in the brain. *Acta Psychologica*, 1967, 27, 5-22.

Whiting, H. T. A. Overview of the skill learning process. *Research Quarterly*, 1972, 43, 266-291.

Williams, L. R. T. Refractoriness of a long movement. *Research Quarterly*, 1971a. 42, 212-219.

Williams, L. R. T. Refractoriness of an extended movement to directional change. Journal of Motor Behavior, 1971b, 3, 289-300.

Woodworth, R. S. The accuracy of voluntary movement. Psychological Review Monograph Supplement, 1899, 3, 54-59.

Woodworth, R. S. and Schlosberg, H. Experimental psychology. (Rev. ed.) New York: Henry Holt and Company, 1954.

Wyrick, W. and Duncan, A. Electromyographic study of reflex premotor, and simple reaction time of relaxed muscles to joint displacement. Journal of Motor Behavior, 1974, 6, 1-10.

APPENDIX A

INSTRUCTIONS - DAY 1

This experiment will require five sessions, each lasting approximately 30-40 minutes. It is essential that you schedule these sessions as close together as possible, i.e., consecutive days would be preferable.

During the first two sessions you will be asked to do two tasks, with each hand. One task will require the lifting of your index finger off of a reaction time key at the sound of a buzzer. The second task will require the lifting of your index finger off of a reaction key, and a subsequent movement routine requiring a series of linear movements and reversals. At each movement reversal a switch is located that must be closed by you in order to obtain movement times at the various locations. Success at this task will be determined by quickness in initiating the movement, and once started, quickness in completion of the movement. I will demonstrate how this may be done in a moment.

The last three sessions will require you to combine combinations of these two responses in close temporal sequences, using alternate hands. A more detailed description of this part of the experiment will be given to you during the third session.

I will now demonstrate the two responses that you will be asked to perform.

Do you have any questions?

SAMPLE DATA SHEET-DAY 1 AND DAY 2

SUBJECT ______________
DATE ______________
TIME ______________

BLOCK →	1		2		3		4		5		6		7		8	
TRIAL #	PI	SR	PI	CR	PI	CL	PI	SL	PI	SR	PI	CR	PI	SL	PI	CL
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																
$\bar{X}$																

INSTRUCTIONS - DAY 3

This is an experiment to determine your reaction and movement speeds under various task conditions. There will be four separate tasks which you will be asked to perform within each daily session. All trials, within a particular task condition will commence when the red warning light comes on. In order to be prepared to make your responses, you should have your left and right hands pressing the appropriate reaction time keys during this period. A variable interval will follow the red warning light's initiation, and then two buzzes will follow one another at variable intervals. In response to the first buzz you will be asked to make a particular response with your left hand, while the second buzz will require a response from your right hand. Often, the second buzz will occur too soon after the first to allow either the initiation or completion of the initial, left-handed response. In this event you are asked to curtail your first response and immediately begin the implementation of the second one. In all trials the second task should be completed. The degree of success of the curtailed first task will be determined by the speed from which you initiate your response, and by the number of switches you successfully close. Frequently, the entire first response may be completed before the second buzz sounds.

By previous research, and an earlier pilot study with this equipment, it has been found that some subjects have a tendency to respond with both hands to the first stimulus. It is emphasized that each hand's response should be performed as quickly as possible, only to the appropriate buzzer, i.e., the left hand responds to the first buzz, and the right hand to the second. Hence, while performing the tasks, pay particular attention to the independence of responses with each hand!

The simple task will simply require the lifting of your finger from the key at the sound of the buzzer.

The complex task will require you to move your hand from the appropriate key, hit a tennis ball directly in front of the key with the back of the same hand, closing a switch attached to the supporting string, reversing direction to hit another reaction time key on the baseboard, and reversing direction again, moving forward and upward to grasp and pull down a second tennis ball, closing another switch.

Each task will have different combinations of these two responses.

Are there any questions?

SAMPLE DATA SHEET-DAY 3, DAY 4, AND DAY 5

SUBJECT ____________________

DATE ____________________

TIME ____________________

TR. ↓	Block 1 = SC				Block 2 = CC				Block 3 = SS				Block 4 = CS			
	PI	ISI	RT_1	RT_2	PI	ISI	RT_1	RT_2	PI	ISI	RT_1	RT_2	PI	ISI	RT_1	RT_2
1	4	8			3	4			3	1			1	2		
2	2	4			2	1			1	8			2	4		
3	3	2			1	8			4	4			4	8		
4	1	1			4	2			2	2			3	1		
5	3	2			1	2			4	2			3	4		
6	1	1			2	1			1	4			1	1		
7	4	8			3	4			3	1			4	8		
8	2	4			4	8			2	8			2	2		
9	2	8			3	8			3	1			4	1		
10	4	1			1	2			2	2			2	2		
11	1	4			4	1			1	4			3	8		
12	3	2			2	4			4	8			1	4		
13	3	2			2	1			2	4			3	4		
14	2	1			3	2			1	8			1	8		
15	1	4			4	4			3	2			2	2		
16	4	8			1	8			4	1			4	1		
17	3	1			4	8			3	4			2	2		
18	1	4			3	1			1	1			4	8		
19	4	2			2	4			2	2			1	4		
20	2	8			1	2			4	8			3	1		
21	4	2			2	2			2	8			3	4		
22	1	4			1	8			1	4			1	8		
23	3	8			3	4			3	2			2	2		
24	2	1			4	1			4	1			4	1		
25	1	8			4	2			2	8			3	8		
26	2	1			2	1			2	4			1	4		
27	4	2			1	4			1	1			2	1		
28	3	4			3	8			3	2			4	2		
29	3	2			4	1			3	1			3	1		
30	1	2			3	2			2	8			4	2		
31	4	8			2	8			4	4			1	8		
32	2	1			1	4			1	2			2	4		
33	2	8			3	1			4	2			2	1		
34	1	2			2	4			2	4			4	4		
35	3	1			1	2			1	8			3	8		
36	4	4			4	8			3	1			1	2		
37	4	4			1	1			1	1			3	8		
38	1	1			4	2			2	8			1	1		
39	2	8			2	4			3	2			2	2		
40	3	2			2	8			4	4			4	4		
C_1	-				-				-				-			
C_2	-				-				-				-			
C_3	-				-				-				-			
C_4	-				-				-				-			
C_5	-				-				-				-			

Subject ______________________

Subject Debriefing

The experiment in which you have just taken part deals with your capacity to amend a movement once begun in favor of one that follows in very close temporal succession. During the last three sessions the second stimulus buzzer followed the first one at random intervals of between 1/10 and 6/10 of a second. The response latencies of the first and second responses were recorded, and will be analyzed subsequently. Briefly, an increased response latency to the second response, above that of a normal reaction time to that task alone (Sessions 1 and 2) has been observed when the second stimulus buzzer occurs during the reaction time period to the first stimulus (the reaction time period to the first stimulus is the interval between the time you heard the first buzzer, and the beginning of your first response). One hypothesis that attempts to explain this phenomenon likens the brain to a single-channel decision processor, i.e., a computer that can deal with only one piece of stimulus or response information at a time, and will hold additional new information, such as the second buzzer, in limbo until it has finished dealing with the first bit of information. Other theories have been posited hypothesizing that the observed increased latency to the second response is due to an expectancy or preparatory state of the subject, i.e., the subject does not expect the second stimulus so soon after the first and thus, is not ready to respond even though, if the subject was ready, a response equivalent to one that is separate could be made. Another theory proposes that perception takes place in quantums, i.e., a sample is taken, and a period exists in which no other sampling can take place, then a perceptual gate opens and another sample taken. Hopefully, the data accumulated from you will aid in resolving which of the above hypotheses fits the results of the experiment best.

Unfortunately, at this time only the simple reaction times to each of the tasks that you performed during the first two sessions are available. In order for you to obtain some information about your own performance, mean values for each of your hands on each of the tasks are given below.

Mean RT-Right Hand Simple Key Release _____	Mean RT-Left Hand Simple Key Release _____
Mean RT-Right Hand Complex Movement _____	Mean RT-Left Hand Complex Movement _____

Subject Debriefing--Continued

For your comparison, the mean reaction time to sound, for a simple key lift response, is approximately 140 milliseconds. In an earlier experiment, that used the same complex movement, reaction time was 219 milliseconds.

Thank you very much for your cooperation.

Donald S. Siegel

APPENDIX B

Table 7

Newman-Keuls Test:

Differences Between Levels of SRC

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	40**	132**	170**	- - - - - - -	25.11
CS		-	92**	130**	- - - - - - -	23.36
SC			-	38**	- - - - - - -	20.52
SS				-		

**p<.01

Table 8

Newman-Keuls Test:

Differences Between Levels of ISI

	100	400	800	200	Critical Values .05	.01
100	-	26**	32**	33**	- - - - - -	15.23
400		-	6	7	11.25	14.17
800			-	1	9.37	12.45
200				-		

**p<.01

Table 9

Newman-Keuls Test:

Differences Between Days

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	18**	26**		12.19
Day 4		-	8*	7.98	10.66
Day 5			-		

*p<.05

**p<.01

Table 10

Newman-Keuls Test:

SRC at ISI 100

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	51**	127**	162**		29.26
CS		-	76**	111**		27.22
SC			-	35**		23.91
SS				-		

**p<.01

Table 11

Neuman-Keuls Test;

SRC at ISI 200

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	44**	129**	165**		29.26
CS		-	91**	121**		27.22
SC			-	36**		23.91
SS				-		

**p<.01

Table 12

Newman-Keuls Test:

SRC at ISI 400

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	36**	166**	209**		29.26
CS		-	130**	173**		27.22
SC			-	43**		23.91
SS				-		

**p<.01

Table 13

Newman Keuls Test:

SRC at ISI 800

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	26**	95**	143**	- - - - - - -	29.26
CS		-	69**	117**	- - - - - - -	27.22
SC			-	48**	- - - - - - -	23.91
SS				-		

$^{**}p < .01$

Table 14

Newman Keuls Test:

ISIs at SRC SS

	100	800	200	400	Critical Values .05	.01
100	-	32**	35**	55**	- - - - - - -	20.93
800		-	3	23**	15.62	19.53
200			-	20**	- - - - - - -	17.21
400				--		

$^{**}p < .01$

Table 15

Newman-Keuls Test:

ISIs at SRC SC

	100	800	200	400	Critical Values .05	Critical Values .01
100	-	19**	40**	47**		20.93
800		-	21**	28**		19.53
200			-	7	13.02	
400				-		

**p<.01

Table 16

Newman-Keuls Test:

ISIs at SRC CS

	400	100	200	800	Critical Values .05	Critical Values .01
400	-	7	32**	33**		20.93
100		-	25**	26**		19.53
200			-	1	13.02	
800				-		

**p<.01

Table 17

Newman-Keuls Test:

ISIs at SRC CC

	100	400	200	800	Critical Values .05	.01
100	-	8	32**	51**		20.93
400		-	24**	26**		19.53
200			-	19**	13.02	17.21
800				-		

**$p < .01$

Table 18

Newman-Keuls Test:

Days at ISI 100

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	18**	29**		16.75
Day 4		-	11	11.08	14.75
Day 5			-		

**$p < .01$

Table 19

Newman-Keuls Test:

Days at ISI 200

	Day 3	Day 4-Day 5	Critical Values .05	.01
Day 3	-	12	13.32	
Day 4-Day 5		-		

Table 20

Newman-Keuls Test:

Days at ISI 400

	Day 3	Day 4-Day 5	Critical Values .05	.01
Day 3	-	10	13.32	
Day 4-Day 5		-		

Table 21

Newman-Keuls Test:

Days at ISI 800

	Day 3	Day 4	Day 5		Critical Values .05		.01
Day 3	-	34**	50**	- - - - - - -		-	16.75
Day 4		-	16*	- -	11.08	-	14.75
Day 5			-				

*$p < .05$

**$p < .01$

Table 22

Newman-Keuls Test:

ISIs at Day 3

	100	800	400	200		Critical Values .05		.01
100	-	20**	35**	41**	- - - - - -		-	19.03
800		-	15*	21**	- - - - - -		-	17.72
400			-	6	-	11.83	-	15.62
200				-				

*$p < .05$

**$p < .01$

Table 23

Newman-Keuls Test:

ISIs at Day 4

	100	400	200	800	Critical Values .05	.01
100	-	27**	35**	36**		19.03
400		-	8	9	14.19	
200			-	1	11.83	
800				-		

**$p < .01$

Table 24

Newman-Keuls Test:

ISIs at Day 5

	100	400	200	800	Critical Values .05	.01
100	-	15*	23**	41**		19.03
400		-	8	26**		17.72
200			-	18**	11.83	15.62
800				-		

*$p < .05$

**$p < .01$

Table 25

Neuman-Keuls Test:

SRCs at Day 3

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	64**	143**	186**		30.94
CS		-	79**	122**		28.89
SC			-	43**		25.41
SS				-		

$^{**}p < .01$

Table 26

Newman-Keuls Test:

SRCs at Day 4

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	37**	129**	168**		30.94
CS		-	92**	146**		28.89
SC			-	39**		25.41
SS				-		

$^{**}p < .01$

Table 27

Newman-Keuls Test:

SRCs at Day 5

	CC	CS	SC	SS	Critical Values .05	.01
CC	-	18	120**	155**		30.94
CS		-	102**	137**		28.89
SC			-	35**	19.19	25.41
SS				-		

**$p < .01$

Table 28

Newman-Keuls Test:

SRC SS Over Days

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	15*	19*	17.37	21.71
Day 4		-	4	14.48	19.13
Day 5			-		

*$p < .05$

Table 29

Newman-Keuls Test:

SRC SC Over Days

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	19*	27**		21.71
Day 4		-	8	14.48	19.13
Day 5			-		

*$p < .05$

**$p < .01$

Table 30

Newman-Keuls Test:

SRC CS Over Days

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	4	6	17.37	
Day 4		-	2	14.48	
Day 5			-		

Table 31

Newman-Keuls Test:

SRC CC Over Days

	Day 3	Day 4	Day 5	Critical Values .05	.01
Day 3	-	33**	50**		21.71
Day 4		-	17*	14.48	19.13
Day 5			-		

*$p < .05$

**$p < .01$

APPENDIX C

Table 32

Raw Data for Day 1 and Day 2

	Simple Right	Simple Left	Complex Right	Complex Left
Day 1				
Mean	153	153	219	224
SD	25	24	30	34
Day 2				
Mean	141	138	195	202
SD	29	28	31	34

N=24

Table 33

Raw Data: RT_1

Group Means

Group	SRC	ISI	100	200	400	800
		Day 3				
Fast	SS		128	134	131	141
	SC		145	144	145	142
	CS		184	178	186	187
	CC		188	180	185	190
Slow	SS		166	163	166	171
	SC		179	193	203	198
	CS		223	220	231	236
	CC		233	233	228	232
		Day 4				
Fast	SS		117	118	122	113
	SC		131	131	135	136
	CS		167	168	161	164
	CC		173	168	169	174
Slow	SS		143	141	153	155
	SC		162	169	166	172
	CS		208	203	213	216
	CC		222	229	220	221

Table 33--Continued

Group	SRC	ISI	100	200	400	800
		Day 5				
Fast	SS		109	111	115	116
	SC		127	124	123	126
	CS		158	164	173	170
	CC		173	166	166	169
Slow	SS		138	143	141	135
	SC		150	158	155	161
	CS		213	207	205	212
	CC		208	208	207	212

Note. Data are in milliseconds.

Table 34

Raw Data: RT_2

Group Means

Group	SRC	ISI	100	200	400	800
		Day 3				
Fast	SS		207	169	152	191
	SC		234	192	184	219
	CS		324	283	313	299
	CC		378	355	365	337
Slow	SS		239	203	198	225
	SC		302	246	252	299
	CS		341	304	337	361
	CC		451	403	396	391
		Day 4				
Fast	SS		201	171	143	160
	SC		226	186	177	197
	CS		306	291	306	270
	CC		339	315	347	291
Slow	SS		233	187	170	200
	SC		273	230	229	255
	CS		349	320	358	315
	CC		412	357	390	362

Table 34--Continued

Group	SRC	ISI	100	200	400	800
		Day 5				
Fast	SS		193	174	145	161
	SC		219	191	172	191
	CS		313	303	339	258
	CC		314	304	339	273
Slow	SS		229	189	164	174
	SC		261	226	212	237
	CS		336	316	355	307
	CC		383	351	390	316

Note. Data are in milliseconds.