A COMPARISON OF FRACTIONATED REACTION TIME AND MOVEMENT TIME IN MALES ACROSS SELECTED AGE AND PHYSICAL ACTIVITY LEVELS

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ABSTRACT

A COMPARISON OF FRACTIONATED REACTION TIME AND MOVEMENT TIME IN MALES ACROSS SELECTED AGE AND PHYSICAL ACTIVITY LEVELS

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The purpose of this investigation was to compare the fractionated reaction time and movement time performance of 120 male subjects across various age and physical activity levels. The subjects were divided into six groups according to age and level of activity. Two young groups included men 20 to 30 years of age, two middle age groups were comprised of men ranging in age from 40 to 51 years and two older age groups were made up of men between 58 and 79 years of age.

The apparatus used consisted of a stimulus unit, a response unit and a recording unit. The stimulus unit was composed of three white lights which were used as the visual stimuli. The recording unit consisted of an oscilloscope and an electromyograph. The response unit consisted of two parts, a hand response unit and a foot response unit. Following the three practice trials, each subject completed a total of 48 trials including 12 hand simple, 12 hand choice, 12 foot simple, and 12 foot choice reaction time trials.

The data were analyzed by multivariate analysis of variance procedures to detect significant differences in the performance of the three age groups or the two activity groups on total reaction time, premotor time, motor time and movement time. Analysis of the data indicated that age generally was a significant factor in total reaction time (i.e., hand simple, hand choice, foot simple and foot choice reaction time), in premotor time, in motor time associated with foot choice reaction time and in movement time. Active males and less active males were not significantly different from each other in terms of total reaction time, premotor time, motor time or movement time. Similar results were obtained when all sixteen reaction time variables were included in one analysis or when they were analyzed in four sets of related variables.

To my wife Farideh,
my mother,
and
in memory of my father

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CHAPTER I

INTRODUCTION

The relationship between reaction time, movement time and age is curvilinear in nature. Studies show that reaction time improves with age until the end of the second decade of life; that little deterioration occurs during the third, fourth and fifth decades; and, that a gradual decline is observed beginning with the sixth decade of life (Hodgkins, 1962; Panek, Barrett, Sterns & Alexander, 1978). Unfortunately, the physiological condition of the subjects in these investigations has been largely ignored.

Some significant questions regarding the role of physical fitness, physical activity, age, and neuromuscular efficiency were raised by Botwinick and Thompson in 1968. These investigators were concerned with the relationship between the life history of individuals and their aging patterns. They assumed that athletic participation resulted in age differences in neuromuscular parameters. Although Botwinick and Thompson (1968) raised these important questions, they failed to include an elderly, active group in their study. Therefore, further investigation is needed to determine the effects of chronic physical activity on the maintenance of neuromuscular integrity.

Total reaction time is not a reliable indicator of central nervous system functioning in regard to aging and physical activity levels (Clarkson, 1978) because total reaction time does not provide separate information about central nervous system and muscle contraction functions. The current study employed an electromyographic technique in order to fractionate total reaction time into premotor time and motor time components, thus making it possible to differentiate between nervous system and muscular system functioning.

Statement of the Problem

The purpose of this investigation was to compare the fractionated reaction time and movement time performances of male subjects across various age and physical activity levels. More specifically, this study was designed to compare the fractionated simple reaction time of the hand and foot, the fractionated choice reaction time of the hand and foot, as well as the movement time of the hand and foot for six groups of male subjects. The six groups represented: (1) young active males; (2) young less active males; (3) middle age active males; (4) middle age less active males; (5) older active males; and, (6) older less active males.

Hypotheses

Three hypotheses were tested in this investigation:

1. For both active and less active groups, there is a deterioration in reaction time and movement time performance with advancing age.
2. Differences in total reaction time between the various age groups are due to a lengthening of the premotor time component rather than the motor time component.

3. There is less deterioration in reaction time and movement time responses with advancing age in individuals who engage in a regular program of physical activity than in individuals who were formerly active or were never involved in a regular program of physical activity.

Need for the Study

Psychologists and physical educators are interested in the slowing of reaction time in the later years of life, not only because of its importance in perceptual-motor skills, but also because of its presumed reflection of central nervous-system functioning (Botwinick, 1965). Weiss (1965) demonstrated that the increase in simple reaction time occurred predominantly in the premotor component of reaction time, which suggested that the greatest detrimental effects of aging are found in the nervous system, rather than in the muscular system.

Several studies have indicated that active elderly persons who participate in physical activity training programs have reaction time and movement time performance scores superior to those of their less active counterparts (Botwinick & Thompson, 1968; Spirduso, 1975; Spirduso and Clifford, 1979; Clarkson, 1978). For example, Spirduso (1975) found that elderly people who maintain an active life style reacted and moved significantly faster and more consistently than elderly non-active people. Even more important, they reacted and moved at least as quickly as young, non-active individuals.

Conflicting results have been obtained when different age groups were compared on total reaction time and fractionated reaction time. Kroll and Clarkson (1977) demonstrated that on total reaction time performance, an old inactive group had the longest reaction time followed by an old active group, a young inactive group and finally a young active group. However, when reaction time was fractionated into premotor time and motor time components, members of the old active group and the old inactive group were significantly different from each other in premotor time only. Moreover, the old active group was similar to the young active group in the premotor time and motor time performance. Therefore, Kroll and Clarkson suggested that the utilization of total reaction time as a single criterion measure of the aging process fails to reveal significant differences in the components of reaction time performance. By fractionating reaction time into premotor and motor time components, more information is derived on the functioning of the central nervous system versus that of the peripheral processing system. To this author's knowledge, no study has focused on fractionated choice reaction time involving the lower limbs with the performer in a standing position. Nor has total body movement time been measured for three different age groups with two different levels of exercise.

Research Plan

The subjects were 120 male volunteers. They were categorized into six groups, 20 in each group, according to age and level of activity. The younger age groups included men 20 to 30 years of age, while the middle age groups and older groups ranged in age from 40 to 51 years and from 58 to 79 years, respectively. The active groups included men who had been involved in physical activity on a regular basis all of their lives. Less active groups included men who did not exercise regularly or who had not participated in regular physical activity for five years or longer. The testing apparatus consisted of a stimulus unit, a response unit, and a recording unit. The stimulus unit was composed of three white lights which were used as the visual stimuli. The recording unit consisted of a digital oscilloscope and a chart recorder with equivalent paper speed of 100 millimeters per second for the foot and 200 millimeters for the hand, respectively. The response unit consisted of two parts, a hand response unit and a foot response unit. The hand response unit included one releasing hand reaction time button and three hand Microswitches placed 25 centimeters apart. The foot response unit was composed of one releasing foot reaction time button and three foot switches placed 30 centimeters apart. At the light stimulus, the subject moved his hand or foot from the reaction time button to the appropriate Microswitch with the greatest possible speed. Following a brief practice period, the subject completed 12 consecutive trials for each of the four reaction time tasks. Multivariate analysis of variance was used to analyze the data that were collected by the above procedure.

Limitations of the Study

This study was subject to several limitations. First, the subjects were volunteers from Michigan State University and the immediate surrounding community. The degree to which these volunteers were representative of the university community or that of the general population would determine the extent to which the results could be generalized. Secondly, the classification of subjects into "active" and "less active" groups within each age category was based on a self-report activity history. The accuracy of these reports was contingent on the validity of the recall as well as the integrity of the subjects.

A third limitation was the inability to secure a group of sedentary subjects. Although the attempt was made, it was not possible to obtain a sufficient number of subjects at each age level who would report themselves as being sedentary. Fourth, the active subjects in this study engaged in different sport activities, therefore, application of the results to a particular sport is not warranted. Finally, the electrodes for obtaining the premotor time measure for the foot were attached to the hamstring muscles. The extent to which activity recorded from this site is not an accurate measure of true premotor time for the various directional movements of the foot should be considered a limitation.

Definition of Terms

Reaction Time. The interval of time which elapses between the presentation of a stimulus that requires a muscular response and the onset of that response.

Movement Time. The time required to move the dominant hand 25 centimeters in one of three forward directions or the dominant foot 30 centimeters in a forward, sideward, or backward direction.

Simple Reaction Time. The time required for a subject to react to a specified stimulus with a prescribed response.

Choice Reaction Time. The time required for a subject to react to stimuli presented randomly with the corresponding prescribed responses.

Premotor Reaction Time. The period of time from stimulus onset to the appearance of a muscle action potential from the muscle responsible for initiation of the response (Fig. 3.2).

Motor Reaction Time. The duration of time from initial muscle firing to the release of the hand or foot from the reaction time button. This measure was obtained by subtracting premotor time from total reaction time.

CHAPTER II

REVIEW OF THE LITERATURE

This study was designed to investigate fractionated reaction time and limb movement time in male subjects grouped according to age and level of physical activity. Since the literature on reaction time is voluminous, this review of the literature will be limited to those studies which are central to the purpose of this investigation. Thus, studies that primarily focus on the relationship of sensory modality, stimulus intensity, intelligence, academic achievement, sex differences, and special populations to reaction time are not included in the review. The chapter is divided into three major sections as follows: (1) age differences in reaction time and movement time; (2) the relationship of physical activity to reaction time and movement time; and (3) studies specifically involving fractionated reaction time.

Age Differences in Reaction Time and Movement Time

Speed of reaction in relation to age has been one of the most extensively studied phenomena in the laboratory investigation of human performance. One of the most reliable and well-documented findings in the literature on age and performance is that the time required by mature adults to perform nearly all activities increases with advancing age. The results of most studies which used subjects across different age spans, from early childhood through the ninth decade, conclusively demonstrated that a significant relationship exists between reaction time performance and chronological age. Significant relationships between chronononological age and movement time scores also have been established in many of the investigations. The review of literature involving age differences in reaction time and movement time will be presented under the following subheadings: (1) age related studies; (2) developmental studies; (3) preparatory interval; (4) perceptual difficulty; (5) stimulus intensity; (6) stimulus alternation versus stimulus repetition; and (7) physiological conditioning.

Age Related Studies

Numerous investigators have studied the nature of the relationship between age and reaction time performance across several decades of life. Of interest has been the determination of the age of maximum performance, the age of greatest consistency in performance, and the age of onset of significant decline in reaction time performance.

The curvilinear relationship of reaction time and chronological age is well documented. In general, investigators report that reaction time improves from birth until approximately twenty years of age, at which point it plateaus for several decades and then decreases as age increases (Bellis, 1933; Pierson, 1957; Mendryk, 1960; Hodgkins, 1962). Bellis (1933) studied the reaction time of 150 males and females sampled at random and ranging in age from 4 to 60 years. He obtained the shortest reaction time scores from subjects between the ages of 21 and 30 years, with a decrease in performance in the younger and older aged subjects. Pierson (1957) studied the reaction time and movement time of 400 male subjects between the ages of 8 and 83 years. He found that both movement time and reaction time were significantly related to chronological age. The fastest movement time and reaction time performances were obtained from men 19 and 20 years of age. However, the greatest stability of individual movement time and reaction time performance resulted from men 26 through 30 years of age.

Junior high school boys and middle age men were found to be slower than college males in both speed of movement and reaction time in a study conducted by Mendryk (1960). He tested three groups of 50 males who were 12, 22 and 48 years of age. Measures were taken of reaction time performance and of movement speed for a short arm-thrust as well as for a longer arm movement involving a circular component. Fifty trials were completed by each subject with the short movement, followed by 60 trials with the long movement. Only the last 30 trials of each movement were analyzed. The 12-year-old subjects were 15 percent slower than the 22-year-old males in both reaction time and the short movement time, and 7 percent slower in the long movement time. The 48-year-old subjects were 13 percent slower than the group of 22-year-old subjects in reaction time, 18 percent slower in short movement time and 21 percent slower in long movement time. All of these differences were significant with the exception of the 7 percent difference involving the long movement.

There were no significant differences between the performance of 12-year-old and 48-year-old subjects on any of the measures.

Hodgkins (1962) examined the influence of age on speed of reaction and speed of movement in 480 girls and women ranging from 6 to 84 years of age. In addition, he investigated the relationship of reaction time to movement time. Results of the study showed that reaction time and movement time were uncorrelated at all age levels, except between the ages of 22 and 37 years. In these females, movement time improved with age up to age 15, remained constant to age 19, and deteriorated thereafter. In contrast, reaction time improved with age up to age 19, remained constant to age 26, and then deteriorated with age.

The general decline in reaction time performance in the later years stimulated interest in the existence of this phenomenon in other speed-related activities. Salthouse (1976) studied the age-performance functions for a variety of speed activities in order to determine if all activities decline at the same rate. The procedure consisted of extracting relative performance measures from five published reports that provided data on a variety of activities ranging from simple reaction time to long distance running events. Salthouse determined the maximum performance for each set of data across all age groups and then computed ratios of performance for each age group to this maximum performance. He found that the steepest age declines are exhibited in the running events. These require approximately 35 to 40 percent more time to complete at age 60 than at age 20. Moderate age declines were evident in the swiftness-of-blow, manual-reach-and-grasp, and reaction time plus motor time activities which are performed approximately 15 to 20 percent slower at age 60 than at age 20. Simple reaction time tasks were performed only 5 percent slower at age 60 than at age 20. Another interesting finding of this study was that the nature of the age function was nearly identical for running events of various distances. For example, there was no indication that age of maximum performance increased with distance, or that speed deteriorated more slowly at longer distances than at shorter distances. He concluded that it is inappropriate to refer to the "slowing with age" phenomenon without specifying the particular activity with which one is concerned.

The differential effects of aging on many reaction time tasks become evident during the late forties and early fifties. However, for simple tasks the aging effects may be delayed until the sixties or even beyond. Panek, Barrett, Sterns and Alexander (1978) selected 175 female volunteers in order to investigate age differences in perceptual-motor reaction time for seven age groups. The age of the subjects ranged from 17 to 72 years. Perceptual-motor reaction time was measured by two levels of tasks: simple choice reaction time and complex choice reaction time. The stimuli for the simple choice reaction time task consisted of four different signals--a green left turn arrow, a red braking disc, a green right turn arrow and a yellow disc for a horn-blow response. Each stimulus was presented six times in random order, to which the subject was to respond appropriately. In the complex choice reaction time task, the stimulus consisted of a photograph of an actual driving scene in which a signal or sign was embedded. Subject responses were the same as those for the simple choice reaction time task. Results of the simple choice reaction time task showed significant differences among the groups. In addition, a trend analysis yielded a significant linear trend. Newman-Keuls analysis indicated that Group 7 (age 65 to 72 years) was significantly slower than the six other groups. Analysis of the complex reaction time scores indicated that there also was a significant linear trend. Newman-Keuls analysis revealed that Group 2 (age 25 to 32 years) was significantly faster than all other age groups and Group 7 (age 65 to 72 years) was significantly slower than the other groups. Groups 1 (age 17 to 24 years), 3 (age 33 to 40 years) and 4 (age 41 to 48 years) were significantly different from each other, but were significantly slower than Group 2 (age 25 to 32 years) and significantly faster than Groups 5 (age 49 to 55), 6 (age 57 to 64 years) and 7 (age 65 to 72 years). Moreover, Groups 5 (age 49 to 56) and 6 (age 57 to 64) were not significantly different from each other, but were significantly faster than Group 7 (age 65 to 72 years) and significantly slower than the other groups.

Nebes (1978) studied vocal response versus manual response as a determinant of age difference in a simple reaction time task. In the two studies reported by Nebes, the type of motor response that the subjects made determined whether or not a significant difference in simple reaction time was found between young subjects and older subjects. In the first study, there was no difference between 20 older subjects and 20 younger subjects in the speed with which they initiated a vocal response to a stimulus. In the second study, simple visual reaction time was measured in 32 young subjects and 32 older subjects using both manual and vocal responses. With the manual response, the typical age difference in reaction time was found. However, with the vocal response, there was no significant difference between two age groups. Thus, Nebe's findings did not support the hypothesis that with age there is a universal slowing in all cognitive operations. Instead, he suggested that whatever the underlying causes for behavioral slowing with age, they do not appear to operate at such a fundamental level that all psychological processes are necessarily affected. In addition, he concluded that the existence of a significant age difference in simple psychomotor latency is dependent on the nature of the subject's response.

<u>Developmental Studies</u>

Several investigators have studied the nature of reaction time performance during the course of growth and development of children (Phillip, 1934; Goodenough, 1935; Jones, 1937; Surwillo, 1971; Surwillo, 1972; Carron & Bailey, 1973; Fulton & Hubbard, 1975; Eckert & Eichorn, 1977). All of these investigators demonstrated a significant releationship between reaction time and development. The nature of this relationship is an improvement in reaction time with increasing age. This reduction in reaction time during the developmental years was revealed in both cross-sectional and longitudinal studies.

In a cross-sectional study, Surwillo (1971) investigated simple auditory reaction time and choice auditory reaction time tasks in a group of 110 boys aged from 46 to 207 months. Electroencephalograms were recorded during performance of simple reaction time and choice reaction time to determine the extent to which differences in reaction time associated with development could be identified by developmental changes recorded in the electroencephalograms. In the simple reaction time task, ten high and ten low tones were presented in random order over an 8-minute interval. For the choice reaction time task the subject was instructed to press the reaction key only to the high tone and to ignore the low tone. As in the simple reaction time, ten high and ten low tones were presented in random order. The results showed a significant relationship between reaction time, standard deviation of reaction time and development. The Pearson product-moment correlation coefficient of -.501 between age and electroencephalogram period was significant. Choice reaction time performance scores showed a more rapid decline with increasing age than those for simple reaction time.

In another cross-sectional study Surwillo (1972) tested 12 boys aged 8.5 to 17 years to discover whether reaction time changed with age in children. The score for each subject was an average value based on 20 trials of the reaction time task taken after the subject had been given ample practice. The correlation coefficient of -.895 between reaction time and age suggested that reaction time improves with age in children. The results of this investigation were supported by the work of Fulton and Hubbard (1975). These investigators measured the reaction time and movement time of the four limbs in children at ages 9, 11, 13, 15 and 17 years. The subjects were random samples of 50 children in each age group. Fulton and Hubbard reported that reaction times and movement times decreased rapidly with age.

A longitudinal study by Carron and Bailey (1973) examined possible changes and individual differences in the reaction time and movement time performance of 146 young boys across the age range from 7 to 13 years. Hand reaction time, movement time and body reaction time data for boys were obtained annually as part of the Saskatchewan Child Growth and Development Study. The subjects were measured for seven years (from ages 7 to 13 years) for hand reaction time and movement time, and also for four years (from ages 10 to 13 years) for body reaction time. Carron and Bailey concluded that total body reaction time decreased steadily as a function of age over the age range examined. Hand reaction time steadily decreased as a function of age from 7 to 11 years of age, but beyond this no further improvement occurred. Hand movement time decreased steadily with age from 7 to 9 years of age beyond which no further improvement occurred. The year-to-year correlations for hand reaction time were generally low, but statistically significant, while those for hand movement time and body reaction time were even lower and mostly non-significant.

Eckert and Eichorn (1977) examined the reaction time of two groups of children in the longitudinal studies at the Institute of Human Development, University of California Berkeley. The purpose was to determine developmental variability in reaction time. Group One was tested for reaction time at yearly intervals from age 4.5 to 11.5 years. The number of subjects tested at various age levels ranged from 18 to 26 for girls and from 22 to 30 for boys. Group Two was measured on reaction time annually for four consecutive years. The ages at testing ranged from 10 through 16 years, and the numbers at these ages ranged from 15 to 75 for boys and from 13 to 89 for girls. The data were grouped by chronological age and sex and by skeletal age and sex for both groups. The results for Group One indicated that there was a consistent and significant improvement in mean reaction times from 4.5 to 11.5 years for both males and females. However, adjacent year comparisons indicated that significant improvement occurred only between ages 4.5 and 5.5 and between 5.5 and 6.5 years for both males and females. Similarly, in Group Two, there was a significant improvement in reaction time from 10 to 16 years for males using either hand. But, only between 11 and 12 years was there a significant annual increment for both hands. There was also a decline in the amount of improvement that occurred with increasing age. The females also showed significantly faster reaction times with increasing age using either the right or the left hand; but again, only between the ages of 11 and 12 years was there a significant annual improvement. However, by age 16, the mean performance had regressed to a level of performance comparable with that at 12 years of age. When the reaction time data were analyzed in terms of skeletal age, significant results were obtained for both males and females. On the basis of skeletal age, the mean reaction time for males decreased steadily from age 8 through 16 years. In contrast, mean reaction time for females decreased only from skeletal age of 8 years through 11 years, followed by trends toward increased mean reaction time.

Preparatory Interval

Preparatory set is, inferentially, a readiness to respond to the appropriate reaction signal. Operationally, it is measured as the variation in reaction time which occurs as a function of variation in the preparatory interval. The preparatory interval is the interval between the onset of the warning signal and onset of the reaction time signal. It is also commonly referred to as the foreperiod. There are two common methods of using the preparatory interval in studies involving preparatory set. These are known as the "regular" and "irregular" procedures. In the "regular" series the length of the preparatory interval remains constant for each trial in the series. In the "irregular" series, the length of the preparatory interval is variable.

The difference in reaction time performance under short and long preparatory interval conditions is greater for older subjects than for younger subjects (Simon, 1968; Thompson & Botwinick, 1968; Elliott, 1970). Simon (1968) conducted an experiment to investigate the signal processing component of reaction time as a function of aging. Simon tested 24 elderly subjects between 64 and 86 years of age and 24 young subjects between the ages of 18 and 21 years. The subjects were instructed to respond to two kinds of test trials, one in which the correct response was to press the key on the same side of the stimulus light and the other in which the correct response was the key on the opposite side. Two sets of warning lights were used, one set positioned on top of the other. If a top warning light came on before the trial, the subject responded with the right key to the right light or the left key to the left light. If a bottom light came on before the trial, the subject responded with the right key to the left light or with the left key to the right light. All subjects performed two blocks of trials. In one block the preparatory interval was 100 milliseconds, and in the other block this interval was 1.5 seconds. Each block consisted of 60 test trials. Half of the subjects in each age group performed the short preparatory interval trials first while the other half performed the long preparatory interval trials first. Analysis of the data revealed that reaction time associated with the short preparatory interval was slower than that with the long preparatory interval. Simon maintained that the difference between reaction times under short preparatory intervals and long preparatory intervals provides a measure of time spent processing the meaning of the warning signal. He reported that the difference in reaction time between the short preparatory interval and long preparatory interval conditions was greater for the older group than for the younger group.

Thompson and Botwinick (1968) studied age differences in relation to electroencephalogram arousal and reaction time. The subjects included two age groups: an elderly group consisting of 16 men and 10 women ranging in age from 67 to 87 years and a younger group consisting of 16 men and 10 women ranging from 19 to 35 years of age. Preparatory intervals of .5, 3.0, 6.0 and 15.5 seconds duration were used for both a regular and an irregular series of stimulus presentations. Electroencephalogram tracings were recorded from the left parieto-occipital area during the middle reaction time trials for each of the different preparatory interval conditions. In all, electroencephalograms were obtained on 82 reaction time trials for each subject. A resting control measurement was also obtained. The results indicated that in the regular series the greatest change in electroencephalogram amplitude occurred during the .5-second preparatory interval for both age groups of subjects. The electroencephalogram change for the older group was greater than for the younger group, but the difference between the two age groups diminished as the preparatory interval durations increased. In the irregular series for older subjects, the maximum electroencephalogram change occurred with the shortest preparatory interval (.5 seconds) while for younger subjects the minimum change occurred with this preparatory interval. The authors reported a statistically significant age difference in reaction time, but not in the electroencephalogram measure. This led to the conclusion that electroencephalogram changes do not explain the slowing of reaction time in older age subjects. Botwinick and Thompson (1968) reported that older adults are more variable in reaction time than younger adults independent of the preparatory interval effect.

In addition to the studies mentioned, Elliott (1970) investigated the effect of age and preparatory interval on the simple auditory reaction time of 288 subjects. There were 24 subjects at each age from 5 through 13 plus 72 young adults. Reaction time scores were obtained from both regular and irregular stimulus presentation procedures. The preparatory intervals were 1, 2, 4, 8 and 16 seconds. Elliott found that children had longer reaction times than young adults and their reaction time performance was affected to a greater degree by the preparatory interval than that of the young adults.

Elderly subjects fail to show an anticipatory response when the preparatory period is long. Loveless and Sanford (1974) conducted an experiment to relate changes in preparatory set to the slow change of cortical potential known as the "contingent negative variation." Two groups of subjects were employed. The first group included 12 young subjects ranging in age from 20.2 to 22.7 years. The second group consisted of 12 elderly subjects who had retired or were close to the age of retirement. Five foreperiods were used, namely .5, 1.0, 3.0, 6.0 and 15.0 seconds. In the regular and irregular sessions, 16 trials at each foreperiod duration were recorded. At the same time, electroencephalograms were recorded from silver chloride cup electrodes spaced along the midline in supra-orbital, frontal, vertical, and parieto-occipital positions. Analysis of data indicated that the poor performance of elderly subjects at long predictable foreperiods is accompanied by a qualitative difference in the form of "contingent negative variation." This outcome was interpreted to be less suggestive of impaired ability to maintain a state of preparation than of difficulty in controlling a sequence of psychological processes so as to initiate preparation at an appropriate time.

Lack of vigilance plays a role in the slowing of responses which has been reported as characteristic of older subjects.

Surwillo and Quilter (1964) conducted a study to investigate the relationship of vigilance to age, and to determine whether lowered vigilance is associated with the age related slowing in reaction time. The subjects were 106 men, ranging in age from 22 to 82 years. Fifty-three of the subjects were under 60 years of age and an equal number of subjects were 60 years or older. The mean age of the young group was 43.7 years and the mean age of the older group was 71.0 years. Mackworth's Clock-Test was used. The clock had a single black pointer, 6 inches in length. This pointer moved in discrete steps. The full circle contained 100 steps, each of which occurred once every second. At long and irregular intervals, the pointer traveled through twice the usual distance in a constant amount of time. These movements were referred to as "double jumps" and in the course of 1 hour 23 such "double jumps" were presented to each subject. The subject's task was to press a response-key as quickly as possible when he recognized a "double jump." The mean percentage of "double jumps" detected by the young group was 72.9 percent while the corresponding value for the old group was 64.4 percent. The difference of 8.5 percent was statistically significant, indicating that, under the conditions of this experiment, older people were less vigilant than young people.

In another study, Surwillo and Quilter (1965) investigated the influence of age on the latency time of involuntary and voluntary responses to the same stimulus. Involuntary response latency was measured by the latency of the galvanic skin reflex while the latency of voluntary response was measured by reaction time performance. The subjects were 132 healthy males, aged 22 to 85 years. The subjects were distributed into 3 groups: a young group ranging in age from 22 to 47 years; a middle aged group ranging in age from 48 to 67 years, and older group from 68 to 85 years of age. The performance for measuring response latency was the same as that used in an earlier study by Surwillo (1964). Results of this study supported the hypothesis that the latency of the galvanic skin reflex increases with advancing age. But the latency of the voluntary responses, as measured by reaction time performance to the same stimuli, showed no increase with advancing age.

Perceptual Difficulty

Several investigators have studied the relationship of reaction time with perceptual difficulty (i.e. information processing, mental rotation of figures, and choice reaction time) across various age groups. These investigators found that speed of response is also a function of perceptual difficulty (Birren & Botwinick, 1955; Simon, 1968; Elliott, 1970; Surwillo, 1973; Birren, 1974; Gaylord & Marsh, 1975). Birren and Botwinick (1955) conducted a study to determine to what extent perceptual difficulty might be a variable in response time across various age groups. The subjects were 30 young individuals aged 19 to 36 years and 43 elderly subjects aged from 61 to 91 years. The young subjects and elderly subjects were required to judge which of two simultaneously presented lines was the shorter. The lines were presented tachistoscopically. Each subject made a minimum of 48 judgments in a series of line pairs which differed in length from 1 to 50 percent. The subject was required to respond as quickly as possible when the stimulus lines were presented by saying "right" or "left" to indicate the position of the shorter line. The vocal response of the subject operated a voice key which interrupted a chronoscope circuit. A significant difference in response time between the two age groups was found at all levels of stimulus difficulty. The response time of the elderly group became relatively slower than that of the younger group as the stimulus difficulty was increased. Thus, the difference in response between the young group and elderly group was 0.47 second for a one percent difference in line length compared to only 0.18 second at a 50 percent line length difference. The authors concluded that perceptual difficulty can contribute to the slower response time of elderly subjects, but that there is a residual age difference in response time which exists regardless of ease of the perceptual task involved.

Old age is accompanied by an increase in information processing time. Surwillo (1973) tested 54 male subjects, aged 34 to 92 years on simple reaction time and choice reaction time tasks. The stimuli, suprathreshold 250 and 1,000 cycles per second tones of equal loudness, were presented an equal number of times at random and without warning during separate experimental sessions. In the first session, subjects performed the simple reaction time task, giving a manual response whenever either tone was presented. The choice reaction time task which followed required the subjects to respond only when the 1,000 cycle per second tone was presented. Sixteen simple reaction time and 11 choice reaction time trials were recorded. The results of the choice reaction time task supported the hypothesis that the time required to process information increases with age. In a related study, Birren (1974) also reported that with advancing age individuals show a tendency toward a slowness in response that reflects a basic change in the speed with which the central nervous system processes information. He suggested that it is not the motor response or muscular strength itself which leads to accident-prone behavior in the aged, but rather an increase in decision time and the inability of the older person to rapidly discriminate relevant from irrelevant information.

Older subjects respond more slowly than younger subjects on a task which requires them to mentally rotate figures. Gaylord and Marsh (1975) compared 10 right-handed young males aged from 18 to 24 years with 10 right-handed elderly males aged from 65 to 72 years to determine to what extent increases in decision time with age can be apportioned to the encoding and motor functions output and to the cognitive processing aspects. Subjects were asked to judge whether pairs of perspectively drawn figures were the same or mirror images of each other. The response times of old subjects and young subjects to "same" pairs were compared; older subjects were shown to have a significantly greater variance. Analysis of the results for two groups indicated that the greater the degree of angular orientational difference, the longer the response time. Linear regression indicated that both the Y-intercept and the slope of the line represented the speed with which the subject could "mentally rotate" the two figures to test for congruence.

Simple reaction time, disjunctive reaction time (choice reaction time with red and green lights), and simple reaction time with alerting signals all deteriorate with advancing age. Talland and Cairnie (1961) tested speed of finger response in three groups of subjects, 20 to 40, 65 to 75, and 77 to 89 years of age, respectively. The measures included reaction time, disjunctive reaction time, and simple reaction time with alerting signals. Analysis of data indicated that older subjects responded significantly slower under all conditions than the younger group and that the oldest group was significantly slower than the middle age group in disjunctive reaction time. Alerting signals resulted in faster reaction time in the youngest group but caused delay in the older subjects. The authors suggested that this paradoxical effect may be due to one or more age connected changes in central processing.

Stimulus Intensity

Studies dealing with the intensity of stimulus indicate that speed of reaction time improves as the stimulus intensity increases. In addition, older subjects are slower in responding to stimuli than their younger counterparts (Botwinick, 1971; Botwinick & Storandt, 1973; Beagley & Sheldrake, 1978). Botwinick (1971) measured reaction time of 48 subjects, in two age groups. Young adult subjects ranged in age from 17 to 22 years and elderly subjects were from 64 to 79 years of age. The purpose was to discover whether or not the elderly subjects had faster reaction times than young adults when both the strength of input and the conditions of set or expectancy are favorable to them. There were three stimulus intensity conditions. In each of these conditions, two regular preparatory interval durations were used: .5 second and 6.0 seconds. Thus reaction time was measured for each of six stimulus intensity-preparatory interval conditions. One of the three stimulus intensities was suprathreshold, the same for all subjects with 81 decibels; the other two were threshold intensities, different in decibels for each subject, but the same or similar in terms of reported loudness. In measuring reaction time, each subject was first presented with the 75 percent threshold intensity--.5 second preparatory interval condition, next 75 percent--6.0 second interval, then the 100 percent--6.0 second interval, the 100 percent--.5 second interval, the suprathreshold--6.0 second interval, and finally, the 81 decibel--.5 second preparatory interval. There were 25 reaction time trials in each intensity-preparatory interval condition. Non-parametric U-test and students' t-tests were carried out for each intensity-preparatory condition to determine whether elderly subjects were slower than the younger adults. The total sample of elderly subjects was slower than that of younger subjects in each of the six conditions with both types of tests. Results indicated that in all cases except those involving the two lowest-intensity stimuli, the differences in reaction time between the weaker and stronger stimulus were greater for the older subjects than for the younger subjects. Even though the differences between the two weakest-intensity stimuli were greater for the elderly group than for the young group, these differences were not statistically significant.

For the purpose of studying age differences in reaction time as a function of stimulus intensity, Botwinick and Storondt (1973) selected 61 female volunteers; 33 subjects ranging in age from 18 to 22 years, and 28 subjects ranging in age from 60 to 84 years. Thirty-two trials were given to each subject with each of six different stimulus intensities: a 750 Hertz tone of 55, 60, 65, 70, 75 and 85 decibels. Reaction time trials were presented with regular preparatory intervals of 0.5 seconds or 6.0 seconds. The first five of the 32 trials for each series were considered practice or warm-up. The last 27 trials were treated as data trials. Results indicated that elderly subjects were slower than young adult subjects, and that up to the point of fairly weak stimulation (55 decibels) they were as slow in relation to auditory stimuli which were loud and easy to perceive as they were to stimuli that were more difficult to perceive. When the intensity of stimulation was systematically decreased, the reaction times of older subjects with a 0.5 second preparatory interval were much slower than when the intensity of stimulation was systematically increased. Beagley and Sheldrake (1978) tested 70 normally hearing subjects in response to clicks at 60, 70, and 80 decibels. They also reported a consistent lengthening of latency with reduction of stimulus intensity.

Stimulus Alternation Versus Stimulus Repetition

A number of studies were conducted to find the effects of frequency of presentation and repetition of stimuli on the reaction time performance of subjects in different age groups. The result of these studies revealed that individuals from different age groups responded to stimulus alternations more rapidly than to stimulus repetition (Waugh, Fozard, Talland & Erwin, 1973; Fozard, Thomas &

Waugh, 1976; Jordan & Rabbit, 1977). Waugh, Fozard, Talland, and Erwin (1973) measured reaction time of 203 male subjects to discover the effects of age and stimulus repetition on choice reaction time. There were 65, 57, 62 and 19 subjects in each of four age groups, 26 to 39, 40 to 49, 50 to 59, 60 to 79 years, respectively. Subjects released one key with the right hand upon presentation of a red light and another key with the left hand when a green light was presented. Each stimulus was presented 20 times for a total of 40 trials. Stimuli on 10 of the trials were the same as on the preceding trial (i.e., they were repeated stimuli); while on the other 30 trials, they were different (or alternated). Results indicated that the average choice reaction time tended to increase with age. Application of Tukey's conservative test for multiple comparisons among means reveals that only the average response times of the oldest and youngest age groups differed significantly. The tendency to respond faster to non-repeated stimuli was statistically significant. A practice effect was observed for the alternated stimuli, but not for the repeated stimuli. Results indicated that in none of the four age groups was there a statistically significant decrease in choice reaction time over trials with repeated stimuli. In contrast, there was an overall decrease in choice reaction time to alternated stimuli for all age groups. The decrease was statistically significant, however, only for the three younger groups. The authors suggested that the predictability of a stimulus, rather than repetition of a particular response, is critical to the conventional "repetition" effect.

A similar study to that of Waugh et al. (1973) was conducted by Fozard, Thomas, and Waugh in 1976. They measured the binary choice reaction times of 123 males aged from 25 to 79 years in a sequence of discrete trials in which the proportion of occasions that the same stimulus light was presented twice in succession varied from .25, .50 and .75 seconds to .75, .50 and .25 seconds over successive thirds of a sequence of 120 trials. The two stimulus lights were presented with equal frequency. The reason for varying the proportion of times that the same light was presented twice in succession was to determine if there were age related differences in the degree to which response speed could be altered by: (a) pre-conceived expectations for repeated or alternated events; or (b) expectations developed during the course of the experiment with the changing proportion of stimulus alternations. Results indicated that the average response times increased with age. Most subjects, regardless of age responded more rapidly to alternated stimuli than repeated stimuli, especially in the proportion of the sequence that contained .75 second stimulus alternations. The difference in response speed to repeated and alternated stimuli was largest in the oldest age group. Expectation of change in an uncertain stimulus sequence was as great or greater in older adults as in younger adults. The difference in average response times to alternated stimuli and repeated stimuli varied according to how frequently the two kinds of events occurred at different points in the sequence; there were no age related differences in sensitivity to those changes.

Contradictory results to those obtained by Fozard et al. (1976) were reported by Jordan and Rabbit (1977). These investigators made an attempt to discover if, and how, practice, compatibility and repetition effects interact with age. Twelve elderly subjects and 12 young subjects were tested. Signals were either a cross or a bar (+ or -) on a red, green or amber background. This was a two-choice task and subjects were instructed to press one key whenever a cross signal appeared and the other key whenever a bar signal appeared. The subjects were told that the colored backgrounds were completely irrelevant to the task and should be ignored. Results were analyzed into repetitions and alternations of sequences and errors made. Data were classified according to repetition of shape (cross or bar) with the same color background, alternation of shape with the same color background, or alternation of color background. Results indicated that young subjects were significantly faster than their counterparts in each of the response classes considered. For both young and old subjects, repeated responses were significantly faster than alternated responses. Within the two classes of repetitions, when both the relevant signal (cross or bar) and irrelevant background color were repeated, the responses were faster than when the irrelevant component was not repeated. This alternation of the irrelevant component significantly increased the processing time for the young subjects. The increase in response time for the old subjects, however, was not significant. It was also found that later in practice, old subjects were making fewer errors than the young subjects, reversing earlier observations.

Physiological Conditioning

Studies investigating the relationship of physiological parameters to reaction time have produced varied results. In these studies, attempts were made to examine the relationship of cardiac cycle, cardiovascular status, heart rate, coronary heart disease and cardiovascular symptoms to reaction time in various age groups.

Reaction time is not related to cardiac cycle either in elderly subjects or in the comparison of these subjects with young adults (Botwinick & Thompson, 1968; Botwinick & Thompson, 1971; Engel, Thorne, & Quilter, 1972). Botwinick and Thompson tested 13 elderly subjects from 68 to 86 years of age and 31 male subjects from 18 to 22 years of age. Reaction time and an electrocardiogram were simultaneously recorded for each subject individually. A warning signal of 0.5 second duration was presented, followed by a preparatory interval of approximately 1.15 seconds and then the auditory stimulus. The R-wave triggered the stimulus either immediately (zero latency), after .2 second, after .4 second, or after .6 second, according to a pre-arranged schedule. For each of the four latency conditions, which were arranged in random sequence, the results indicated that the time from the R-wave in cardiac cycle latency was not a significant factor in determining whether reaction time was fast or slow. Botwinick and Thompson not only failed to demonstrate a relationship between reaction time and time of stimulation within the cardiac cycle, but they also failed to demonstrate that age groups differed with respect to possible relationships between these two variables. Engel, Thorne, and Quilter (1972) failed to find evidence of any significant tendency of individuals, or groups, to exhibit reaction times which were in any way determined by the electrical events of the cardiac cycle. They reported that reaction time was longer during expiration than during inspiration; however, this effect was most likely attributable to coincidental differences in foreperiod than to the breathing cycle itself.

The relationship between cardiovascular status, age and reaction time performance has been studied by several investigators (Birren & Spieth, 1962; Obrist, Howard, Sutterer, Hennis, & Murrell, 1973; Abraham & Birren, 1973; Botwinick & Storandt, 1974). Birren and Spieth (1962) studied the correlation between age, response speed, and cardiovascular functions. Subjects were 161 healthy men between the ages of 23 and 60 years. The number of individuals in each decade was 29, 39, 65, 23 and 5, respectively. A total of 33 variables were interrelated. These included 15 different psychomotor speed measurements obtained with the psychomet. The psychomet is an instrument developed at the National Institute of Mental Health that consists of a subject's panel containing ten lights and ten keys, and an experimenter's panel on which the associations between lights and keys are programmed and the speed and accuracy of the responses are registered. The physiological measurements were: diastolic and systolic blood pressure; pulse rate before, immediately after, and two minutes after a standardized exercise step test; and, fasting blood sugar and serum cholesterol levels. Of 32 possible correlations with chronological age, 26 correlations were significant at the one percent level. The correlations were higher between the psychological measurements and age (.59 for psychomet) than between age and the physiological measurements (.28 for diastolic blood pressure and .25 for serum cholesterol level). Birren and Spieth suggested the slowness of psychomotor performance with advancing age is not a direct result of the trend toward elevated blood pressure in healthy men.

The relationship between heart rate and somatic-activity during a reaction time task was measured in several age groups. The relationship between heart rate and measures of task irrelevant somatic activity (vertical eye movements and eye blinks, chin electromyograph, and general activity) during a simple reaction time task was evaluated by Obrist, Howard, Sutterer, Henns, and Murrell (1973) in four groups of children and young adults. The number of subjects in each group was: 4 year olds, N = 38; 5 year olds, N = 34; 8 year olds, N = 38; 10 year olds, N = 39; adults, N = 33. The preparatory interval ranged from 1 second to 4 seconds. Sixty simple auditory reaction time trials were given. The first five trials were practice. The results of the study indicated that deceleration of heart rate and a decrease in the several parameters of ongoing task-irrelevant somatic activities were found to coincide with the responses of the adults and of the children in all four age groups. Developmental or age-related differences among these measurements were seen on three somatic measures; namely, eye movements, frequency of eye blink, and chin electromyograph. For these three measures, the magnitude of the phasic decrease was associated with increasing age. Such an age related phase effect was not evidenced with heart rate and general activity. Large age-related differences also were found with tonic levels of heart rate, general activity, chin electromyograph, and eye movements. These tonic levels of activity decreased with age.

Persons behaviorally predisposed to coronary heart disease have slower reaction time than persons who are not predisposed to coronary heart disease. Abrahams and Birren (1973) measured reaction time of 48 males aged from 25 to 59 years. Based on a Standard Situation Interview, 24 coronary-prone Type A subjects and 24 non-coronary prone Type B subjects were identified. The data of analysis for each subject were the means of 50 simple reaction time and 50 choice reaction time trials. The results of this investigation showed that in the absence of clinical signs of pathology, persons behaviorally predisposed to coronary heart disease had significantly longer response latencies in both simple and choice reaction time and were disproportionally slower in choice reaction time than those persons who are not predisposed to coronary disease. Abrahams and Birren concluded that in the absence of clinical signs of coronary heart disease Type A subjects manifested psychomotor characteristics similar to persons already suffering from the disease. They reported that perhaps psychomotor slowing existed prior to the acute onset of coronary heart disease and may be the consequence of psychophysiological antecedents to the disease.

Some cardiovascular symptoms are associated with quick response. Botwinick and Storandt (1974) studied the effect of the cardiovascular status of subjects on reaction time. They used the

Cornell cardiovascular self report scores which ranged from zero symptoms to 7 symptoms. These scores were categorized into two groups: a high group which included individuals with 3 or more symptoms and a low group containing those persons with 2 or fewer symptoms. The results of the analysis of variance indicated that the effect of cardiovascular symptoms, as reported on the Cornell cardiovascular check list, upon the dependent variable of reaction time was significant. Individuals with fewer cardiovascular symptoms had quicker reaction time scores than persons with more symptoms.

The Relationship of Physical Activity to Reaction Time and Movement Time

Aging individuals commonly are observed to substantially decrease the amount of daily physical activity in which they engage. Consequently, it is often speculated that their physical fitness levels are lower than those of younger persons. Successful participation in athletic activities also has been found to be closely related to reaction time. While differences in reaction time between athletes and non-athletes have been found, the exact reasons for these differences remain unknown. It is possible that reaction time, rather than being limited to a function of age, might also be a function of an individual's level of fitness.

Physical Training

The effects of physical training on the reaction time of individuals with low fitness levels have received little attention. To the best of the author's knowledge, there is only one study which has dealt with the effects of physical training on reaction time.

Tweit, Gollnick, and Hearn (1963) tested 20 low fitness subjects to find whether the total body reaction time of individuals can be improved by participation in a strenuous physical training program. The subjects ranged in age from 17 to 21 years with an average age of 18.8 years. Total body reaction time was measured by having the subject stand on two contact plates with feet parallel. When one of the two lights appeared, the subject stepped diagonally forward with the foot indicated by the visual stimulus. Before and immediately after the training program, 20 total reaction time measures were recorded for each subject. Between the initial and final testing, the subjects participated in a vigorous physical training program for six consecutive weeks. Each subject was required to attend four of five 30-minute training sessions which were conducted Monday through Friday of each week. Approximately 50 percent of the training program was devoted to a battery of vigorous exercise designed to develop the large muscle groups of the body. The remaining 50 percent of the program consisted of participation in speed ball, relays, sprints, and weight training. The basic objective of the program was to improve the subject's physical fitness. Analysis of the data indicated that at the conclusion of the six-week training period, the subjects had faster total body reaction times than prior to the onset of the training program.

Active Versus Non-Active

There is general agreement among investigators that a life style of physical activity postpones the decrements in neuromuscular functioning that are attributed to aging (Botwinick & Thompson, 1968;

Gore, 1972; Spirduso, 1975; Spirduso & Clifford, 1978; Clarkson, 1978). Botwinick and Thompson (1968) designed a study to investigate the influence of age and activity on reaction time. They used 13 elderly non-active men from 68 to 86 years of age and 37 young men ranging in age from 18 to 27 years. The young men were divided into athletic and non-athletic groups. Each subject completed 120 reaction time trials. The preparatory interval was set at approximately 1.0 second. Analysis of data revealed that the reaction time of the young athletic group was faster than that of the young non-active group and was also faster than that of the elderly non-active group. Botwinick and Thompson suggested that lack of exercise may be a factor in the slowing of reaction time with age. Unfortunately, they failed to include an elderly active group in their research design.

The influence of physical activity on reaction time and movement time was examined by Spirduso (1975). She conducted a study to determine whether older men who are physically active have significantly faster simple reaction time, choice reaction time and movement time performance than older non-active men. Comparisons were also made with active and non-active young men. The subjects were 60 male volunteers categorized into four groups according to age and sports activity. The young groups included men who ranged in age from 20 to 30 years, while the older groups ranged from 57 to 70 years of age. Fifteen trials of simple reaction time and 15 trials of choice reaction time were administered, but only the last 10 trials of each measure were used in the analyses. Movement time was recorded for all trials. Results indicated that in all variables except choice reaction time, the ascending order for the speed of reaction time and movement time of the groups was: young active, older active, young non-active, followed by the older non-active group. In choice reaction time performance means of both the younger groups were faster than those of the older groups. The young active group was faster than the young non-active group and the older non-active group was significantly slower than the other three groups. Spirduso suggested that vigorous sports participation was a significant factor in retarding the onset of aging. The Spirduso (1975) study was replicated by Spirduso and Clifford in 1978 and again it was shown that older men who maintain an active life style react and move significantly faster and more consistently than their sedentary peers.

The gradual decline in reaction time performance as a function of increasing age may be delayed in trained subjects. To determine if leading a physically active life has any influence on cognitive performance as one grows older, Sherwood and Selder (1979) administered visual simple reaction time and visual choice reaction time tests to 64 male and female volunteers ranging from 23 to 59 years of age. One half of the subjects were runners involved in vigorous training programs averaging 42 miles per week. The other half of the subjects were sedentary adults. Eighty simple reaction time and 100 choice reaction time trials were given with a variable foreperiod ranging from 400 to 100 milliseconds. The results showed that there was a gradual decline in reaction time performance in sedentary adults as age increased. However, this trend was not evident in the trained group. Reaction time remained constant with age within the trained group.

Body Composition

In spite of the fact that reaction time and muscularity are considered as two important factors for successful performance in the game of football, not many investigators have studied the relationship of reaction time to body composition. The relationship between body composition measures, reaction time and run times, at 5, 15 and 40 yards for 48 college football players was investigated by Crews and Meadors (1978). Each player's optimal playing weight was predicted and the effect of being above or below one's predicted optimal playing weight on reaction time and run times was evaluated. Both reaction time and run time were obtained during a 40-yard run. A multiple timing system was designed to obtain the times at the designated distances. Body composition was assessed for all subjects and Predicted Optimal Playing weight was determined using body composition data of professional football players as guidelines. Negative correlations between percent fat and run times were found to increase as the distance increased. The players who weighed more than their predicted optimal weight were found to have slower reaction times (but not significant) and significantly slower run times than those players who weighed less than their predicted optimal weight.

Physical Stress

The relationship of reaction time in the peripheral visual field with level of physical conditioning also has been investigated

(Reynolds, 1976; Rotella & Bunker, 1978). Reynolds (1976) conducted a study to determine: (1) if reaction time in the peripheral visual field and size of the functional visual field were altered by augmented levels of physical stress while performing on a bicycle ergometer; and (2) to determine the relationship between conditioning and reaction time in the peripheral visual field during periods of physical stress. Twenty-three female volunteers between the ages of 20 and 28 years served as subjects. Eleven subjects were initially evaluated as conditioned and 12 subjects were evaluated as unconditioned on the basis of performance on a bicycle ergometer. Each subject was required to pedal a Colins Pedal Model ergometer, which monitored heart rate and pedal speed and automatically adjusted the workload so that a pre-set heart rate was achieved and maintained throughout the testing. The pre-set heart rate was 160 beats per minute. The work load differed for each subject since the desired effect was to stress the subjects uniformly. While pedaling the bicycle, the subjects were required to fix their attention on a central light. The subject's task was to keep this central light lit by pressing a microswitch on the right handlebar grip. The light was extinguished by a computer program set to extinguish the light at predetermined, unevenly spaced intervals. While the subject was pedaling and concentrating on the central task, eight lights mounted perimetrically in the periphery were illuminated one at a time in a random order established by the computer program. The subject's task was to extinguish the peripheral lights dispersed on a horizontal plane as she became aware of them by pressing the

Microswitch mounted on her left handlebar grip. The heart rate of the subject was monitored throughout the testing. Heart rate was recorded at 30 seconds, 1 minute, and 5 minutes after the cessation of the 12 minute exercise period. The recovery heart rate of the subject determined her classification into the conditioned or unconditioned group.

After the subject had spent sufficient time learning the task, base line data were collected. These data were the subject's recorded reaction times for the 12-minute peripheral light program while sitting on, but not pedaling, the bicycle ergometer. The last session was conducted with the subject pedaling the ergometer. Non-correlated t-tests were used to analyze base line data to determine if the groups were significantly different before the exercise portion of the study was begun. No significant difference was discovered between the groups, thus it was concluded that subsequent significant differences would be attributed to the experimental effect. The data were divided into two parts: (1) lights responded to; and (2) lights missed. The lights responded to by the subject provided the experimenter with reaction time values. During the riding periods, there was a significant difference in reaction time between the conditioned group and unconditioned group. The mean reaction time for the conditioned group on all lights was .635 seconds while that for the unconditioned group was .703 seconds. An analysis of the missed lights showed that there existed a significant difference between misses on the right side compared to misses on the left side for both groups. More light presentations were missed on the right side than on the left side. During the riding period, the unconditioned group missed significantly more light presentations than the conditioned group. On the basis of the statistical findings, the following conclusions were made. Reaction time in the peripheral field did not increase as a result of augmented stress. Neither did reaction time increase uniformly with augmented levels of stress. There was no narrowing of the functional visual field as a result of the exercise stress.

Elderly active persons are more field independent and have faster reaction time than their non-active counterparts. Because of the relationship between the ability to attend selectively to a stimulus and the obvious utilization of selective attention in tennis, Rotella and Bunker (1978) selected 20 male tennis players with median age of 72.5 years who participated in the national super-senior tournament and compared the scores of these 20 male tennis players to a non-random control group of 50 volunteer subjects with a median age of 71.8 years. Each subject was tested for field independence utilizing the portable rod-and-frame apparatus, which determines each subject's ability to use visual and proprioceptive cues in establishing the upright in two-dimensional space. Each subject was presented a series of 8 rod-and-frame positions, rotated from right to left for a 28 degree deviation. The subject's score was the mean of deviations from 0 degrees on the eight settings of the rod. Times to respond to a stimulus were determined for each subject on three separate measures utilizing an Athletic Performance Analyzer: simple reaction time, whole body reaction time, and total body response time. Simple reaction time was measured as the time elapsed between the illumination of a single light and the depression of a response button held in the subject's preferred hand. Whole body reaction time was the time between stimulus presentation and the subject's lifting of his body off a mat. Total body response time was the time consumed from the stimulus signal until the subject had jumped from one mat to a second mat located 3 feet directly in front of the subject. Results indicated that the super-senior tennis players were significantly more field-independent than the control group. These findings suggested that the tennis players are more able to attend the significant elements in a visual field. The tennis players also exhibited faster simple reaction times and total body response time than their control counterparts.

Fractionated Reaction Time

In the typical reaction time experiment, it is impossible to dissociate the time required to process the stimulus from the time required to execute the response, thus, the reason for the observed age decrement cannot be determined. The recent development of a technique to fractionate total reaction time into nervous system and muscle contraction latencies shows promise as a means for further studying the question of central nervous system versus peripheral involvement in reaction time performance. Moreover, by using the fractionated reaction time technique, the contribution of the premotor time and motor time components to the deterioration of reaction time in relation to the aging process can be quantified. Research based upon an electromyographic technique which fractionates total reaction time into a premotor, or central, component and a motor, or peripheral, component has led to two different conclusions. Some of the investigations have reported that the cause of age related lengthening of reaction time is due to change in the quality of central nervous system processing rather than in speed of muscular contraction (Birren & Botwinick, 1955; Weiss, 1965; Kross & Clarkson, 1977; Clarkson, 1978), but others reported the involvement of both central nervous system processing and muscular contraction functions in this phenomenon (Botwinick & Thompson, 1966; Botwinick & Thompson, 1966).

Central Versus Peripheral Processing

The changes in reaction time associated with increasing age are not due to the length of peripheral pathways, but rather are a function of information processing within the central nervous system (Birren & Botwinick, 1955). Birren and Botwinick (1955) compared the performance of thirty-two subjects between the ages of 18 and 36 years, and thirty-two subjects between the ages of 60 and 91 years in simple auditory reaction time for the finger, jaw, and foot. The purpose of the study was to determine if the elderly subjects showed a disproportionate slowing of foot responses compared with those of the finger and jaw. The hypothesis was that the slowing of reaction time with advancing age was correlated with the pathway length of the peripheral nerves. The results showed that the age change in reaction time was not associated with the length of the peripheral pathways. Birren and Botwinick found, however, that the reaction times of the elderly subjects were significantly slower than those of the younger subjects.

Weiss (1965), in a simple auditory reaction time experiment, used irregularly ordered preparatory intervals of 1, 2, 3 and 4 seconds to test the hypothesis that the major changes in reaction time associated with the preparatory interval, motivation, and age occur in the central nervous system rather than in the periphery. The subjects were two groups ranging in age from 18 to 30 and from 65 to 80 years, respectively. He theorized that changes in reaction time, due to motivational set or length of preparatory interval, occurred predominantly in the premotor component and were, therefore, seen primarily as central rather than peripheral phenomena. Computation of comparative conduction times in the peripheral nervous system suggested that the differences obtained were largely accounted for by central nervous system functions.

Other evidence suggests that elderly subjects are slower than young subjects in both the premotor and motor time components. In 1966, Botwinick and Thompson conducted an experiment to investigate components of reaction time in relation to age and sex. They segmented reaction time into two component parts, premotor time and motor time. Reaction time and its components were analyzed in relation to four preparatory intervals within an irregular series and a regular series. These functions were then compared among subgroups comparing elderly males, elderly females, young adult males and young adult females. Electromyograms were recorded from the extensor muscle of the responding forearm during measurement of reaction time. The time between stimulus presentation and occurrence of increasing firing was the premotor time. Motor time was reaction time minus premotor time. Analysis of the data indicated that the two elderly age groups were statistically slower than their younger controls, that is, motor time, premotor time, and reaction time were slowed with advanced age when subjects responded to stimuli in either the regular or irregular preparatory interval series. Interactions between age and sex were not significant, indicating that whatever the antecedent mechanisms of the slowing process with advanced age may be, they are the same for men and women.

The fact that reaction time is highly correlated to premotor time and poorly correlated with motor time supports the notion that the aging effect is more a central than a peripheral phenomenon. Botwinick and Thompson (1966) fractionated reaction time into a premotor time component and a motor time component based upon the difference between electromyograms and finger lift responses. The subjects were 34 men and 20 women. The mean age of the subjects was 21.3 years and they ranged in age from 18 years to 35 years. Electromyograms were recorded from the extensor muscle of the responding forearm during measurement of simple auditory reaction times. Four preparatory intervals of 0.5, 3.0, 6.0 and 15.0 seconds were used in both a regular series and an irregular series. In the regular series, 21 stimulus presentations were administered for each of the four preparatory intervals. The order within the irregular series was prearranged so that each preparatory interval duration preceded the other three preparatory intervals the same number of times. Eighty-five reaction time trials were necessary with the irregular preparatory intervals. Electromyograms were recorded for the middle reaction times within each preparatory context. Thus, of the 21 reaction times per regular preparatory interval, electromyograms were recorded for trials 7 to 16. Similarly, the electromyograms were recorded for only the middle 42 reaction times within the irregular series, i.e., trials 22 to 63. The results indicated that premotor time and reaction time were highly correlated (from .87 to .96) and showed comparable variation as a function of preparatory interval and type of series. Motor time was poorly correlated (from +.21 to .55) with reaction time and was independent of preparatory intervals and type of series. It was concluded that reaction time is a premotoric process, and probably a central one.

Premotor reaction time and motor reaction time do not change as a function of movement extent. Lagass and Hayes (1973) studied the effect of variations in extent of movement on fractionated reaction times in 18 male subjects. The mean age of subjects was 23.2 years. Subjects attended two testing sessions on separate days. At each session the subject sat with his fist placed on a Microswitch and ulnar aspect of his forearm resting on a table. The angle between his arm and forearm was 155 degrees. Fractionated reaction times were recorded under two different conditions both of which consisted of simple reaction time. Task A consisted of 25 trials of a simple reaction time to a visual stimulus and involved a rapid withdrawal of the fist from its resting position on the Microswitch. The 25 trials of Task B were initiated in the same way as Task A but continued as rapid flexion of the forearm through a full range of 140 degrees. After 90 degrees of flexion, subject's fist hit the second Microswitch mounted on a freely movable hinge. Task A and B differed only in the extent of movement. Results revealed that the difference between Day 1 and Day 2 means was not significant, for the total reaction time of Task A. For total reaction time of Task B, the large extent movement, a significant difference between Day 1 and Day 2 was found. Motor reaction time for Task A and Task B did not change significantly from Day 1 to Day 2. Similarly for premotor reaction time of Task A, no significant difference was found between Day 1 and Day 2. A significant difference was revealed, however, for the premotor reaction time of Task B between Day 1 and Day 2. The improvement in total reaction time for Task B from Day 1 to Day 2 was, therefore, due to the premotor reaction time component, as the movement time remained constant from Day 1 to Day 2. Analysis of variance testing for differences between the total reaction time means of Task A and Task B revealed no significant differences. Analysis of the fractionated components similarly revealed that motor reaction time and premotor reaction time for Task B were not significantly greater than those of Task A.

Finding the difference between ipsilateral premotor reaction time and contralateral premotor time was the subject of one investigation. Wyrick and Duncan (1974) conducted a study to determine whether a significant difference exists between ipsilateral premotor time and contralateral premotor time. When the two ipsilateral premotor times and contralateral premotor times were compared, the contralateral (mean = 71.9 milliseconds) was significantly faster than the ipsilateral (mean = 88.1 milliseconds). The effect of trials was significant and the side of body by trials interaction was also significant.

Muscular Tension and Exercise Regimen

It is well accepted that skilled motor performance is highly dependent upon optimum timing and coordination of muscular action. Therefore, it is important to know whether the locus of changes in reaction time as a function of muscular tension, activity level, and exercise regimen are more central or peripheral. Schmidt and Stull (1970) investigated the changes in motor time and premotor time components of reaction time as a function of preliminary muscular tension. It was hypothesized that if increased preliminary tension shortens premotor reaction time, the locus of change was central; if increased tension shortens motor reaction time, the effect was peripheral. Subjects squeezed a hand grip device to one of 3 submaximal tensions of 2.2, 19.9 and 37.4 pounds, and reacted to a buzzer by squeezing as quickly and forcefully as possible. Total reaction time appeared to decrease slightly from pretension levels of 2.2 to 19.9 pounds and then to increase slightly from 19.9 to 37.4 pounds, with no regular pattern of change. These differences in total reaction time were not significant. Premotor reaction time appeared to shorten between pretension levels of 2.2 to 19.9 pounds, and remained nearly constant between 19.9 pounds and 37.4 pounds, representing a mean decrease of 9 percent, which was significant. Contrary to the decrease in premotor reaction time, motor reaction time appeared to increase regularly with increasing pretension, with a mean change of 17 percent. This difference was also significant.

Apparently, the effect of pretension was to increase the motor reaction time and to decrease the premotor reaction time. Therefore, the results nearly cancelled each other so that no change in total reaction time could be noted. The main conclusion was that both the central and peripheral components of reaction time changed with increasing pretension, but that they changed in opposite directions.

Lags in central nervous system processing are independent of lags associated with the rate of muscular tension development. Santa Maria (1970) obtained premotor time and motor time scores from 24 male subjects using a knee flexion task. It was predicted that an increased arousal state due to proprioceptive feedback from stretched hamstring muscles would shorten premotor reaction time, while motor reaction time would shorten because of changes in muscle tension development due to alternations in the contractile components of the muscle tissue. A finger reaction time task was also included in order to determine whether other factors not related to change in the stretch of the hamstring muscles were operative. She found that motor reaction time decreased with increased muscle stretch and constituted 46 percent of leg reaction time. Premotor reaction time, as well as finger reaction time, increased rather than decreased with increased muscle stretch. The correlation coefficients between premotor reaction time and motor reaction time were negative but not significantly different from zero. The mean correlation coefficient was equal to .25. The fact that there was no relationship between these two components indicated that central nervous system processing time and rate of tension development within the local muscular system are independent processes.

Simple fractionated reaction time is not a reliable indicator of the onset of muscular fatigue. Kroll (1974) assessed fractionated reaction time for knee extension while the subjects were seated on an experimental table. The study was designed to consider effects of fatigue due to muscular exercise upon reaction time. Stable fractionated reaction times from well practiced subjects were assessed before, during and after an exercise regimen designed to induce fatigue. Subjects were tested over four stabilization days. On the fifth day, six bench-stepping bouts were administered to the subjects. Each bout consisted of 1,383 kilograms per meter of work at a stepping rate of 30 steps per minute. After each bout fractionated reaction time was assessed. Total reaction time remained stable over the bench-stepping exercise ranging from a low of 244.9 milliseconds following bout 4 to a high of 249.6 following bout 3. The total reaction time following the last bout of bench-stepping was 247.4 milliseconds, compared to a pre-exercise baseline reaction time of 246.0 milliseconds. None of the observed reaction time differences were significant. Both premotor time and motor time demonstrated no significant changes due to the exercise regimen.

Some evidence shows that total reaction time and premotor time improve from day-to-day under certain conditions. Morris (1976) measured the fractionated reaction time of 20 male college students to determine the effects that varying amounts of daily practice of a simple visual reaction time task following randomly presented foreperiods will have on total reaction time and its fractionated components. Each subject met with the investigator on four successive days at approximately the same hour. The subjects were assigned to one of four practice groups. Subjects in Group 20 responded to one set of 20 trials per day, subjects in Group 40 responded to two sets of 20 trials per day, and subjects in Group 60 and 80 responded to three and four sets of 20 trials per day, respectively. The single visual stimulus appeared after preparatory intervals of 1, 2, 3, or 4 seconds. Separate analyses were employed for total reaction time, premotor reaction time, and motor reaction time. The analysis of total reaction time indicated significant effects for days and for preparatory intervals or set. The results for premotor time were similar to those for total reaction time in that the effect of set, or length of the preparatory interval, and the effect of day were significant. The results for motor time indicated that neither variation in level of practice nor days was significant. Similar results were obtained for the effect of foreperiod duration.

Fractionated reaction time is quite sensitive to levels of activity and the adverse effects of aging. The effects of age and activity level on simple and choice fractionated response time have been studied by Clarkson (1978). She measured the simple and choice knee extension response time of four groups of subjects: Old Active, Old Inactive, Young Active, and Young Inactive. Each response time measure consisted of total reaction time plus movement time. Total reaction time was further fractionated into premotor time, which represents the central processing component, and motor time which represents the peripheral muscular component. All simple and choice fractionated response components demonstrated an age-related lengthening with motor time showing the least amount of lengthening. Although activity level enhanced the speed of all components in aged subjects, movement time was affected to the greatest extent and motor time was affected the least. Clarkson concluded that (1) motor time is little influenced by age and level of activity and (2) the deterioration in speed of movement with age is almost completely negated by activity in old active subjects.

Summary

On the basis of the results of previous studies the following statements appear justified:

1. The shortest reaction times are between the ages of 20 and 30 years with decrements occurring at earlier and later years.
2. The greatest stability of individual movement and reaction times occurs between the ages of 26 and 30 years.
3. All activities do not decline at the same rate, thus it is inappropriate to refer to the "slowing with age" phenomenon without specifying the particular activity with which one is concerned.
4. Developmental studies of reaction time indicate a reduction in reaction time with increasing age.
5. The decrement in reaction time performance under short to long preparatory interval conditions is greater for older subjects than for younger subjects.

6. Lack of vigilance plays a significant role in the slowing of responses which is characteristic of older subjects.
7. Perceptual difficulty contributes to the slower response time of elderly subjects, but there is a residual age difference in response time which exists regardless of the ease of the perceptual task involved.
8. Reaction time is a function of stimulus intensity, improving as the stimulus intensity increases. In addition, older subjects are slower in responding to stimuli than their younger counterparts.
9. Individuals from all age groups respond to stimulus alternations more rapidly than to stimulus repetition.
10. Speed of reaction in various age groups is not related to cardiac cycle and cardiovascular status of subjects. However, speed of reaction is related to heart rate, coronary heart disease, and cardiovascular symptoms.
11. Physical training improves the speed of total body reaction in young adults.
12. A life style of physical activity postpones the decrements in neuromuscular functioning that are attributed to aging.
13. In the game of football, the players who weigh more than their predicted optimal weight are found to have slower reaction times.
14. Reaction time in the peripheral visual field does not increase as a result of augmented stress. There is no narrowing of the functional visual fields as a result of

exercise stress. In addition, elderly active persons are more field independent and have faster reaction times than their non-active counterparts.

15. The changes in reaction time associated with increasing age are not due to the length of peripheral pathways, but rather are a function of central nervous system processes.

16. Lags in central nervous system processing are independent of lags associated with the rate of muscular tension development.

The review of the literature reveals that there is limited research concerning the fractionated reaction time and movement time performance in relation to age and activity levels. Since the changes in reaction time associated with increasing age are not due to the length of peripheral pathways but to central nervous system processing (Botwinick, 1955; Weiss, 1965; Kroll & Clarkson, 1977; Clarkson, 1978), the possibility exists that differences in total reaction time between subjects at various ages and activity levels are due more to change in the quality of central nervous system processing than to change in speed of muscular contraction.

CHAPTER III

EXPERIMENTAL METHOD

This study was designed to compare the fractionated reaction time and movement time performances of male subjects grouped according to age and level of physical activity.

Subjects

The subjects were 120 male volunteers from the University community at Michigan State which included students, faculty and other university personnel. Some of the subjects were obtained through personal contact outside the main university library and in various intramural locker rooms. Others were recruited via telephone calls to university faculty and staff members and by contacting agencies for the elderly in the community. The subjects were divided into six groups according to age and level of physical activity. Two groups included men 20 to 30 years of age, two middle age groups were comprised of men ranging in age from 40 to 51 years and two older age groups were formed with men between 58 and 79 years of age.

The men in one group at each age level were physically very active whereas the men in the second group at each age level were physically less active. The active groups included men who had been involved in physical activity on a regular basis most of their lives and who presently run, swim or engage in other kinds of vigorous physical activity for a minimum of 45 minutes at least three times per week. The less active groups included men who did not exercise regularly in their youth or who had stopped participating in physical activity on a regular basis during the past five years or longer (See Table 3.1).

Subjects agreeing to participating in the study were sent information about the procedures and requirements of the study. See Appendix A for the sample of these methods.

Table 3.1 -- Distribution of subjects by age and physical activity level

Group	Age Range	Mean Age	N
1. Young Active	20-30	23.5	20
2. Young Less Active	20-30	23.7	20
3. Middle Age Active	40-51	46.2	20
4. Middle Age Less Active	40-51	46.4	20
5. Older Age Active	58-79	64.2	20
6. Older Age Less Active	58-79	65.0	20

Testing Environment

All subjects were tested in the same location, with the same testing equipment and by the same investigator. The testing station was part of a room that could be secured from outside disturbances and that was not subject to extreme variations in temperature and humidity. The subjects were tested individually with only the experimenter and the subject present during the collection of data. Each subject was tested while in a rested condition. Half of the trials were attempted with the subject standing and the remaining trials were made with the subject seated at a table.

The Apparatus

The apparatus consisted of a stimulus unit, a control unit, a response unit and a recording unit. The stimulus unit was composed of a wooden box with three white lights mounted on the front surface, each 15 centimeters apart (See Figure 3.1A). This unit was hung on a wall in front of the subject.

The control unit contained selector switches for hand/foot, stimulus choice (lights 1, 2 or 3), and stimulus delay time (1-3 seconds); a start button; a warning buzzer and circuits necessary to generate the waveforms seen in Figure 3.2 A schematic drawing of the control unit is shown in Appendix C.

The recording unit consisted of a digital storage oscilloscope (Gould model OS4000/4001) and a Gilson multi-channel recorder. The oscilloscope was needed because of the very short time intervals being observed (less than 1 second). Without it, a recorder having a paper speed of 200 mm/sec and extremely fast pen response (less than 2 msec) would have been required. Both the recorder and paper costs would have been excessive. Here, the oscilloscope was used as an intermediate recording device to record and store the data in real time. For this purpose, sweep speeds of .1 sec/cm (hand) and .2 sec/cm (foot) were used. Data were then read out of storage at a slower rate (2 sec/cm) and recorded on paper (paper speed = 10 mm/sec), giving an equivalent paper speed of 200 mm/sec (hand) and 100 mm/sec (foot). Errors in paper speed were corrected via time marks at .05 second intervals superimposed on channel A (See Figure 3.2). Due to the finite sampling rate of the oscilloscope, overall system time errors were ± .0022 second (hand) and ± .0044 second (foot).

The response unit consisted of two parts, a hand response component and a foot response component. The hand response unit included one releasing hand reaction time button and three hand Microswitches placed 25 centimeters from the releasing button and 15 centimeters from each other. The hand reaction time button and the three hand Microswitches were mounted on a wooden board (See Figure 3.1B). The foot response unit was composed of one releasing foot reaction time button and three foot switches placed 30 centimeters from the releasing button and from each other (See Figure 3.1C). The foot reaction time button and the three foot switches were mounted on a second board.

The three stimulus lights, hand switches and foot switches were all connected to the control unit. When the start button was pressed, a buzzer sounded; following the selected delay, the appropriate stimulus light was turned on and a baseline shift was introduced into both oscilloscope channels, signifying the start of total reaction time (See Figure 3.2). Release of the hand reaction button or foot reaction button in response to the stimulus light caused a second baseline shift in channel A only; this point defines the end of total reaction time and the beginning of movement time. Contact with the correct hand or foot Microswitch caused a return of

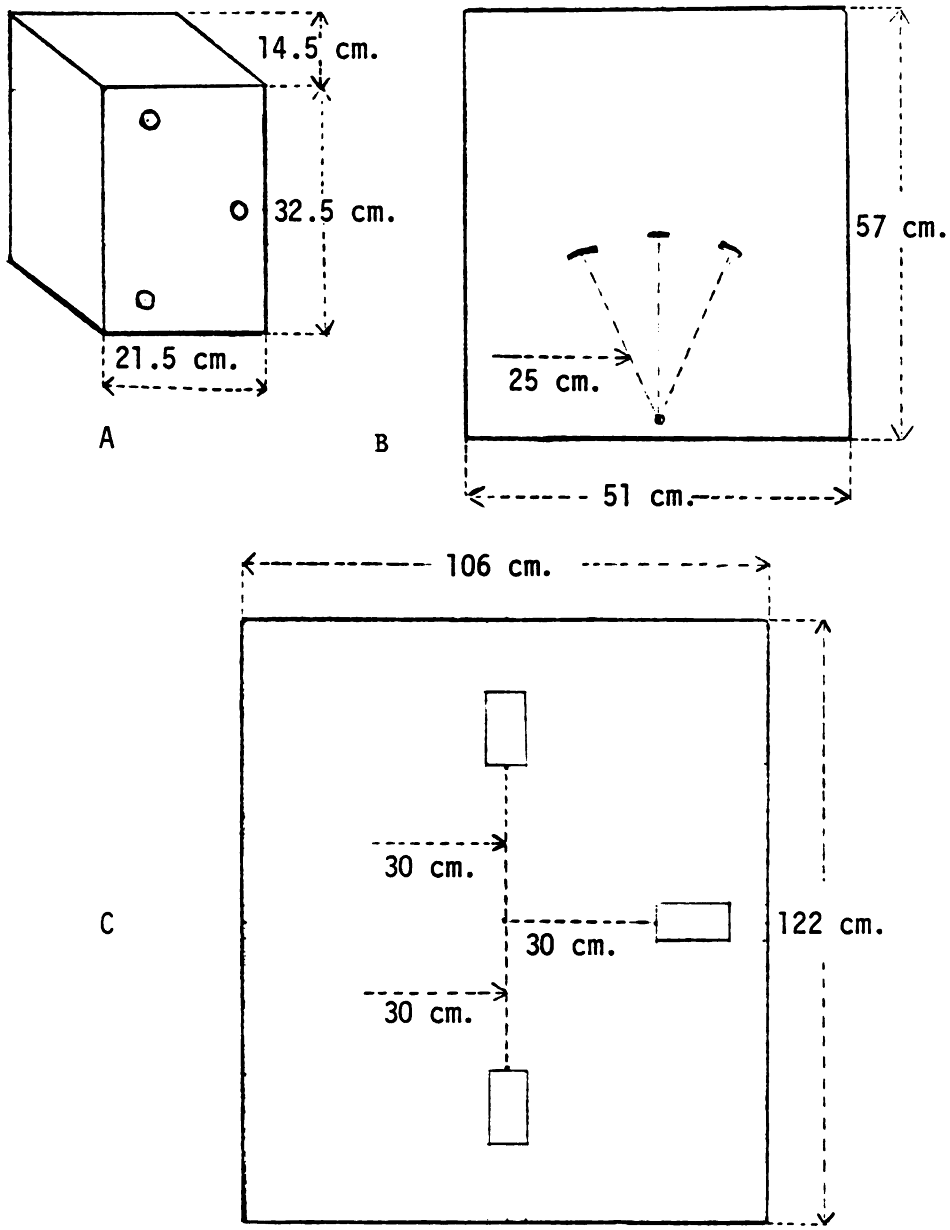

Figure 3.1 - The apparatus for measuring reaction time and movement time: A. Stimulus unit; B. Hand response unit; and C. Foot response unit.

the baseline in channel A to its original position, corresponding to the end of movement time.

In addition to the timing information on channel A, an electromyogram was recorded on channel B to permit fractionation of reaction time. Surface electrodes were placed over the motor points of the finger extensor muscle (extensor digitorum) and the knee flexor muscles (hamstrings). The interval between the baseline shift on channel B and the first observed muscle potential greater than background "noise" represented premotor reaction time. Motor reaction time was obtained by subtracting premotor reaction time from total reaction time.

Following each trial, data stored in the oscilloscope were immediately transferred to the Gilson recorder for later analysis; this analysis consisted of measuring premotor reaction time, total reaction time and movement time from the paper in millimeters with a ruler, and converting these to time values from the known (equivalent) paper speed.

Simple reaction time and movement time were measured by the presentation of the top light on the stimulus unit. Random presentation of the three lights served as the stimulus for obtaining measures of choice reaction time and the corresponding movement times. An example of a simple reaction time trial for the foot is presented in Figure 3.2

Testing Procedure

The subjects were scheduled for testing on a random basis according to their availability. Testing took place at various

TRT = Total reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

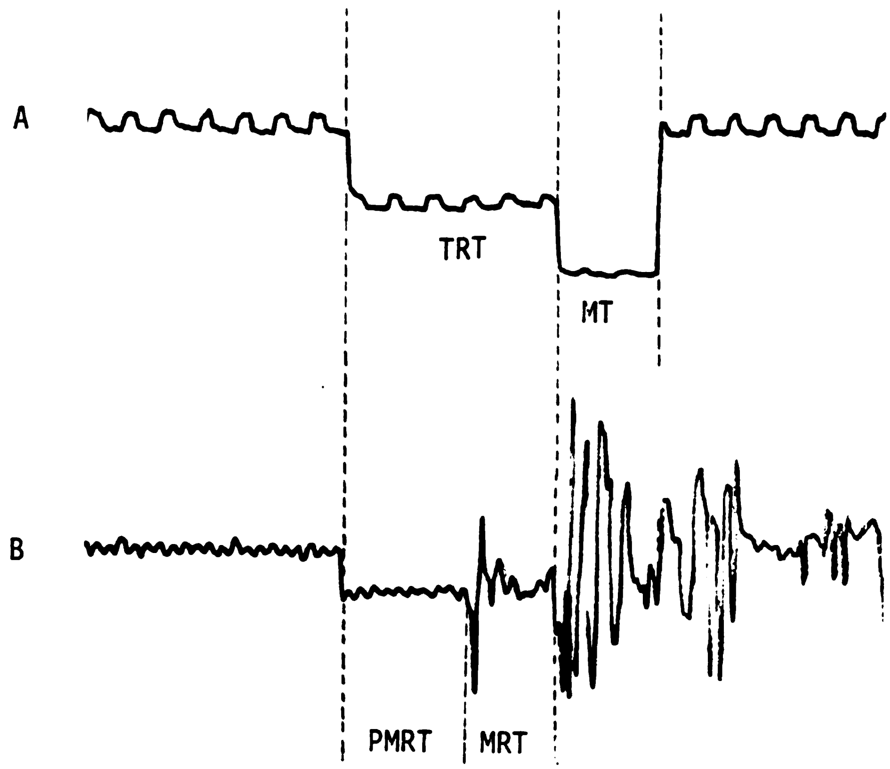

Figure 3.2 - Sample record of simple-foot reaction time and movement time: A. Deflection line for stimulus and microswitch events, and B. Electromyogram.

time intervals between 9:00 A.M. and 6:00 P.M. All data were collected during the spring and summer of 1980.

Upon entering the testing area, the subjects were introduced to the equipment and prepared for the attachment of the required electrodes. After the electrodes were attached, the procedures for the foot reaction time tasks were explained.

The subjects were placed in a standing position, with the dominant foot positioned over the releasing reaction time button. They were told to adjust their position until they could comfortably touch each of the foot microswitches. The stimulus unit was hung on the wall in front of the subjects approximately at eye level. A warning signal, the sound of a buzzer, was given prior to each trial. The time between the warning signal and presentation of the stimulus was randomly varied by half second units from one to three seconds. At the stimulus of light, the subject was to move his dominant foot with the greatest possible speed from the reaction time button to the appropriate foot Microswitch. For the simple reaction time task, the subject moved his foot to the Microswitch directly in front of the releasing button. On the choice reaction time task, the subject moved his foot forward, sideward or backward to the Microswitch designated by the stimulus light.

A similar procedure was followed with the hand reaction time tasks, except that the subjects were seated at a table. The hand reaction time tasks always were administered after the foot reaction time tasks so that the effects of fatigue would be minimized.

Three practice trials were given to the subjects for each condition (simple-foot, choice-foot, simple-hand and choice-hand) to permit them to become familiar with the equipment and procedures. Following each practice period, the subjects completed 12 consecutive trials for each condition. The 12 trials for choice reaction time always followed the 12 simple reaction time trials to permit a simple-to-complex progression in task requirements for each limb.

Each subject also was asked to complete a biographical form so that appropriate demographic information and activity history was obtained (See Appendix B). On the basis of this activity history, the level of activity for each subject was determined.

A pilot study was conducted during the winter term of 1980 to determine the adequacy of the procedures as well as the appropriate set of trials necessary for obtaining consistency in performance. Since no learning effects were evident after a few practice trials and the attention of the subjects seemed to wane after 12 trials, it was decided to limit the number of trials for each measure to twelve. Thus, a total of 48 trials including 12 simple-hand, 12 choice-hand, 12 simple-foot, and 12 choice-foot reaction time trials were obtained from each subject. The mean of each set of 12 trials was used as the performance score of each subject for each of the variables under investigation.

Statistical Design

The means and standard deviations for each of the reaction time and movement time measures were calculated. A two factor crossed design was used. The independent factors were age and activity levels, while the mean of the selected set of trials on each of the fractionated reaction time and movement time measures represented the dependent variables. The data were analyzed by multivariate analysis of variance to detect any significant differences in the performance of the six groups of males on the various reaction time and movement time measures. The level of significance was set at .05.

CHAPTER IV

RESULTS AND DISCUSSION

This study was designed to compare fractionated reaction time and limb movement time of six groups of male subjects. The six groups consisted of: (1) young active males, (2) young less active males, (3) middle age active males, (4) middle age less active males, (5) older active males, and (6) older less active males.

The results portion of this chapter will begin with a presentation of descriptive statistics involving the performance means and standard deviations of the six groups of males on specific reaction time and movement time variables, followed by Pearson product correlation coefficients between the 16 dependent variables. The second section contains the results of multivariate analysis of variance (MANOVA) for significant differences between activity levels and age groups as they relate to each of the hypotheses. The discussion portion of the chapter offers a rationale for the results obtained as well as comparisons with the outcomes of previous investigations whenever appropriate.

Results

Six groups of male volunteers ranging in age from 20 to 79 years were involved in the study. Each subject was given three practice trials for each of the testing situations to become familiar with the procedures for obtaining the reaction time and movement time scores. Following the practice trials, each subject completed a total of 48 trials which included 12 simple reaction time trials (hand), 12 choice reaction time trials (hand), 12 simple reaction time trials (foot) and 12 choice reaction time trials (foot). These data were analyzed with Version 6.1 of the Finn Multivariate Program (Finn, 1978).

Descriptive Statistics

The means and standard deviations for each of the reaction time and movement time measures for the hand and the foot are presented in Tables 4.1 and 4.2, respectively. The mean values are also depicted graphically in Figures 4.1 through 4.4. A general age trend is apparent when examining the graphs. Reaction time and movement time performance deteriorated most notably in the two older age groups on all 16 measures, and generally more so in the less active group.

Differences between the young and middle age groups, both active and less active, are not as apparent. In general, the young active males performed better than their less active peers on the twelve reaction time measures while the reverse was true for the four movement time values. In contrast, the reaction time performance of the less active middle age males (40-50) either equalled or surpassed that of the active males. However, the movement time performance of the latter was superior to that of the less active middle age males.

Table 4.1 - Means and standard deviations for the fractionated hand reaction time and movement time scores

Variable	Active						Less Active					
	Young (20-30)		Middle Age (40-50)		Older Age (58-79)		Young (20-30)		Middle Age (40-51)		Older Age (58-79)	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
HAND												
(Simple)												
RT*	.278	.034	.278	.039	.289	.052	.282	.033	.278	.041	.321	.059
PMRT	.202	.029	.205	.027	.201	.033	.204	.033	.203	.025	.236	.047
MRT	.077	.017	.074	.019	.088	.023	.077	.012	.075	.021	.084	.024
MT	.145	.034	.145	.027	.181	.049	.145	.031	.159	.046	.176	.055
(Choice)												
RT	.294	.038	.321	.044	.346	.056	.314	.040	.316	.048	.348	.050
PMRT	.222	.029	.246	.033	.254	.040	.234	.040	.240	.038	.268	.042
MRT	.077	.021	.075	.018	.091	.030	.081	.017	.076	.018	.081	.026
MT	.154	.039	.149	.048	.185	.044	.151	.029	.161	.037	.185	.053

*RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

Table 4.2 - Means and standard deviations for the fractionated foot reaction time and movement time scores

Variable	Active						Less Active					
	Young (20-30)		Middle Age (40-50)		Older Age (58-79)		Young (20-30)		Middle Age (40-51)		Older Age (58-79)	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
FOOT (Simple)												
RT*	.345	.059	.364	.069	.383	.076	.360	.035	.357	.049	.405	.067
PMRT	.195	.031	.204	.043	.218	.052	.193	.023	.199	.036	.221	.032
MRT	.150	.039	.159	.035	.166	.033	.166	.033	.158	.029	.182	.041
MT	.162	.033	.162	.038	.187	.047	.156	.033	.164	.037	.183	.045
(Choice)												
RT	.377	.051	.427	.077	.465	.082	.401	.048	.423	.064	.478	.073
PMRT	.250	.034	.279	.057	.304	.064	.256	.047	.277	.057	.302	.045
MRT	.128	.025	.148	.025	.161	.029	.147	.029	.148	.029	.176	.041
MT	.186	.040	.182	.041	.215	.052	.181	.034	.194	.040	.232	.060

*RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

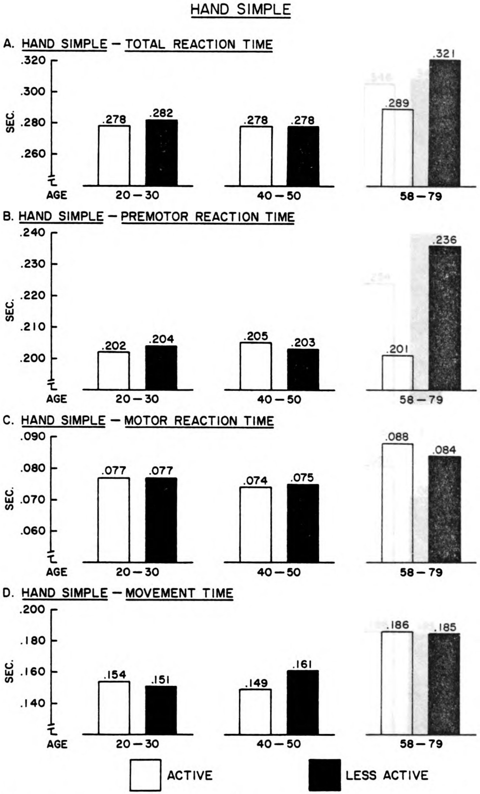

Fig. 4-1. Mean performance of active and less active males on hand simple reaction time and movement time measures.

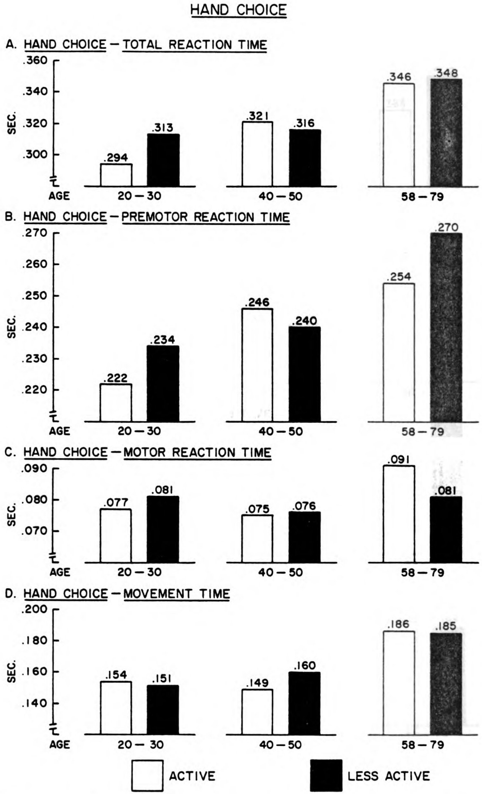

Fig. 4-2. Mean performance of active and less active males on hand choice reaction time and movement time measures.

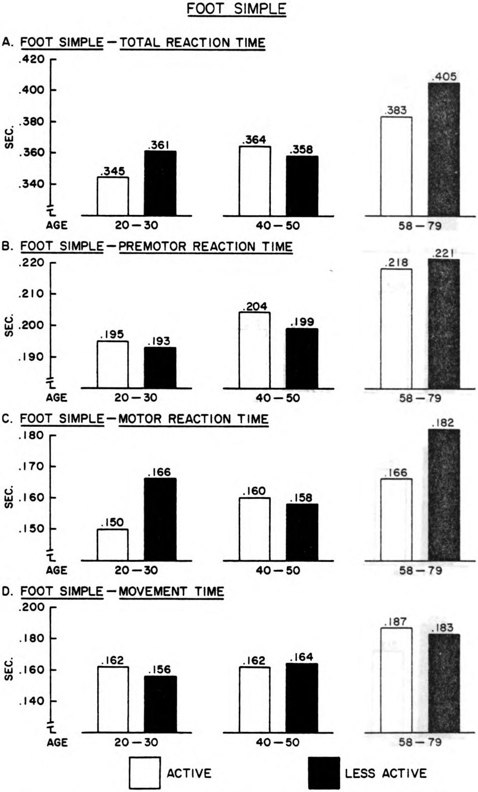

Fig. 4-3. Mean performance of active and less active males on foot simple reaction time and movement time measures.

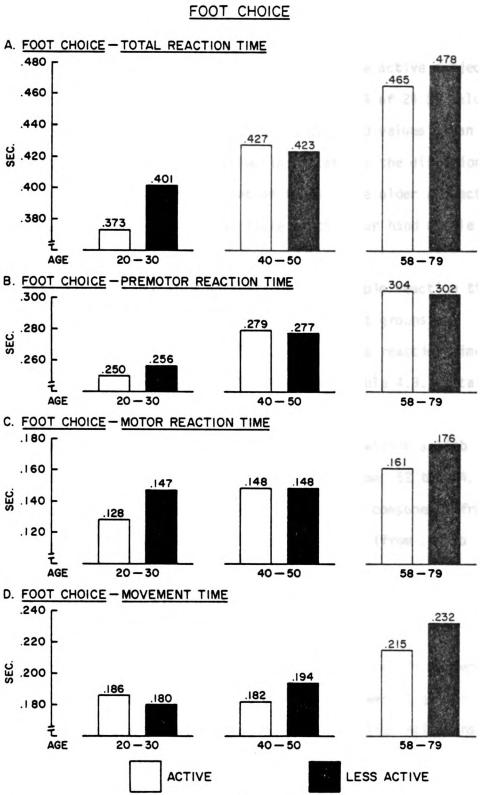

Fig. 4-4. Mean performance of active and less active males on foot choice reaction time and movement time measures.

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There are no definite patterns in performance variability among the age groups on the various reaction time and movement time measures (See Tables 4.1 and 4.2). However, the active subjects tended to be less variable on the hand tasks (14 of 24 SD values) and more variable on the foot tasks (16 of 24 SD values) than the less active subjects. In only two instances was the direction of variability constant across a set of tasks. The older age active males were consistently less variable on the four hand simple reaction time tasks (Table 4.1) and the middle age active males were consistently more variable on the four foot simple reaction time tasks (Table 4.2) than their respective contrast groups.

The intercorrelation matrix for the twelve reaction time and four movement time variables is presented in Table 4.3. Total reaction time measures do not correlate highly with each other. Although the correlation coefficients reach the mid .70s within a limb (simple and choice), between limb values only ranged from .52 to .64. Total reaction time correlated well with its premotor component (from .84 to .89), but less well with its motor component (from .58 to .83). This difference is probably due, in part, to the fact that the premotor component constitutes the major portion of the total reaction time score.

The Pearson product moment correlation values for movement time were moderate to high. Intralimb coefficients were high for the hand (r = .93) and foot (r = .85) whereas interlimb relationships were moderate ranging from .66 for hand choice and foot choice to .78 for hand simple and foot simple. It should be noted, however,

Table 4.3 - Pearson product moment correlation coefficients between the various measures of reaction time and movement time

Variable	Hand Simple				Hand Choice				Foot Simple				Food Choice			
	RT	PMRT	MRT	MT	RT	PMRT	MRT	MT	RT	PMRT	MRT	MT	RT	PMRT	MRT	MT
Hand Simple																
RT *	1.00															
PMRT	.889	1.00														
MRT	.701	.309	1.00													
MT	.422	.324	.395	1.00												
Hand Choice																
RT	.760	.698	.508	.698	1.00											
PMRT	.587	.671	.156	.178	.869	1.00										
MRT	.568	.292	.759	.406	.577	.1362	1.00									
MT	.377	.303	.332	.929	.330	.174	.362	1.00								
Foot Simple																
RT	.585	.517	.432	.569	.517	.376	.382	.5736	1.00							
PMRT	.571	.530	.360	.363	.487	.377	.316	.320	.835	1.00						
MRT	.400	.330	.355	.577	.370	.214	.320	.631	.828	.389	1.00					
MT	.389	.279	.399	.780	.360	.189	.380	.724	.600	.376	.618	1.00				
Food Choice																
RT	.580	.533	.396	.587	.637	.511	.435	.587	.767	.640	.639	.624	1.00			
PMRT	.522	.498	.319	.379	.617	.546	.345	.377	.644	.678	.401	.422	.894	1.00		
MRT	.385	.316	.339	.623	.344	.191	.361	.624	.591	.263	.712	.646	.688	.297	1.00	
MT	.479	.321	.500	.721	.412	.244	.404	.661	.564	.369	.566	.853	.578	.407	.574	1.00

*RT = Reaction time
PMRT = Premotor reaction time
MRT = Motor reaction time
MT = Movement time

that the within limb movement task was the same for both the simple and choice response conditions.

Relationships between total reaction time and movement time are low to slightly moderate. The coefficient values ranged from .33 between hand choice reaction time and hand choice movement time to .60 between foot simple reaction time and foot simple movement time. In general, the coefficients between foot reaction times and foot movement times were higher than those for the hand. Moreover, the values for simple reaction time and simple movement time were higher than the coefficients for choice reaction time and choice movement time.

Inferential Statistics

The data were subjected to multivariate analysis of variance (MANOVA) procedures in order to examine the effect of the sixteen reaction time and movement time variables across the three age groups and the two levels of activity. All sixteen dependent variables were included in the first MANOVA. Subsequently, separate MANOVA procedures were applied to the four total reaction time measures, the four premotor reaction time variables, the four sets of motor reaction time scores and the four movement time variables, respectively. Follow-up procedures including planned comparisons, examination of univariate F values and discriminant function analysis were used when significant multivariate results were obtained. These results are presented in terms of the three hypotheses tendered in Chapter One.

Age and Reaction Time. The first two hypotheses dealt with the effects of age on reaction time and movement time performance. According to the first hypothesis, a deterioration in reaction time and movement time performance would occur with advancing age for both the active and the less active activity groups. In the second hypothesis, it was postulated that such differences in reaction time across the age groups would be due to changes in the premotor component rather than in the motor component of reaction time.

MANOVA procedures applied simultaneously to all sixteen dependent measures yielded a significant main effect for age (Table 4.4). The multivariate F statistic of 1.898 was significant with P less than .004. Examination of the univariate F values revealed that eight of the sixteen variables were significant at the .003 level. (The .003 level was used to preserve the multivariate .05 alpha criterion.) Significant age effects were noted for two reaction time variables (hand choice and foot choice), two premotor time measures (hand choice and foot choice), one motor time measure (foot choice) and three movement time variables (hand simple, hand choice and foot choice). There was no significant age by activity interaction effect.

When separate analyses were conducted for each of the four sets of four variables (i.e., reaction time, premotor time, motor time and movement time) twelve of the sixteen variables were significant (Table 4.5). In addition to the eight variables identified in the previous analysis, hand simple and foot simple reaction time, foot simple premotor time and foot simple movement time

Table 4.4 Multivariate analysis of variance for age effects on sixteen measures of reaction time and movement time

Variable	Univariate		Multivariate	
	F	P	F	P
Hand Simple				
RT **	4.610	.012		
PMRT	2.818	.064		
MRT	3.531	.033		
MT	6.014	.003*		
Hand Choice				
RT	8.836	.0003*		
PMRT	7.506	.001 *		
MRT	2.324	.103		
MT	7.318	.001 *		
Foot Simple				
RT	5.166	.007		
PMRT	4.975	.008		
MRT	2.782	.066		
MT	5.078	.008		
Foot Choice				
RT	15.055	.0001*		
PMRT	9.434	.0002*		
MRT	10.925	.0001*		
MT	9.444	.0002*	1.898	.004*
Interaction (Age by Activity)			1.302	.142

Note - All Probability values were rounded to the nearest .001 unless otherwise noted.

* Significant at the .05 level for the multivariate F and at the .003 level for univariate F's.

**RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

Table 4.5 Multivariate analysis of variance for age effects on each set of four measures of reaction time, premotor time, motor time and movement time

Variable	Univariate		Multivariate	
	F	P	F	P
Reaction Time				
Hand Simple	4.610	.012*		
Hand Choice	8.836	.0003*		
Foot Simple	5.166	.007*		
Foot Choice	15.055	.0001*	4.601	.001*
Interaction (Age by Activity)			1.480	.160
Premotor Time				
Hand Simple	2.818	.064		
Hand Choice	7.506	.001*		
Foot Simple	4.975	.008*		
Foot Choice	9.434	.0002*	3.068	.0003*
Interaction (Age by Activity)			1.654	.111
Motor Time				
Hand Simple	3.531	.033		
Hand Choice	2.324	.103		
Foot Simple	2.782	.066		
Foot Choice	10.925	.0001*	3.367	.001*
Interaction (Age by Activity)			0.827	.580
Movement Time				
Hand Simple	6.014	.003*		
Hand Choice	7.318	.001*		
Foot Simple	5.078	.008*		
Foot Choice	9.444	.0002*	2.966	.004*
Interaction (Age by Activity			0.825	.581

Note - All Probability values were rounded to the nearest .001 unless otherwise noted.

* Significant at the .05 level for multivariate F's and at the .012 level for univariate F's.

performance contributed significantly to the age effect. Reduction of the number of variables in each analysis to four permitted a P value of .012 or less to be used as the alpha level for the univariate F's. However, since four MANOVAs were applied, the probability of a Type I error also is greater than .05. Again, there were no interaction effects between age and activity in any of the four analyses.

The results of these analyses either partially or completely supported the first hypothesis. Under the more conservative analysis, MANOVA with sixteen variables, the two choice reaction time variables (hand and foot) showed deterioration with age as did three of the four movement time variables. Only the movement time associated with the foot simple reaction time task did not exhibit significant age effects (Table 4.4). When the four reaction time variables and the four movement time variables were analyzed in separate MANOVAs, all eight variables contributed significantly to the age main effect (Table 4.5), thus providing full support for the first hypothesis.

The second hypothesis dealing with the two components of reaction time was partially supported by both analyses. It was hypothesized that deterioration in reaction time with age would occur to a greater extent in the premotor time component than in the motor time component. Only two of the four premotor time measures (hand choice and foot choice) were significant in the sixteen variable MANOVA (Table 4.4) whereas three of the four measures were significant with the four variable MANOVA (Table 4.5). The additional variable was the premotor component for foot simple reaction time. Only the foot choice motor time component showed deterioration with age. This result occurred with both analyses (Tables 4.4 and 4.5).

Additional analyses were conducted to determine between which groups the changes in performance took place. Two planned comparisons were made: (1) between the young males and the older age males; and (2) between the middle age males and the older age males.

The first contrast, the young males versus the older males, was significant when all sixteen dependent variables were included in the analysis (multivariate F = 2.546, P less than .003). Inspection of the univariate F values indicated that five of the variables contributed the most to the age differences in performance (Table 4.6). These included hand choice and foot choice reaction time, hand choice and foot choice premotor time, and foot choice motor time. The results of discriminant function analysis identified the most powerful of these variables to be foot choice reaction time, followed in order by hand choice reaction time, foot choice premotor time, hand choice premotor time and foot choice motor time (Table 4.7). The standardized coefficients for foot simple reaction time (-4.215), foot simple premotor time (2.657) and foot simple motor time (1.823) also were high, but their respective univariate F values were not significant. Therefore, the role of these variables in contributing toward the age difference in performance is not clear. The interaction effect for age and activity was not significant.

Table 4.6 Planned comparison test between young males and older males on sixteen measures of reaction time and movement time

Variable	Univariate F	Univariate P	Multivariate F	Multivariate P
Hand Simple				
RT**	1.816	.180		
PMRT	1.692	.196		
MRT	0.681	.411		
MT	5.108	.026		
Hand Choice				
RT	10.125	.002*		
PMRT	10.585	.002*		
MRT	0.233	.631		
MT	4.606	.034		
Foot Simple				
RT	4.334	.040		
PMRT	5.164	.025		
MRT	1.650	.202		
MT	3.827	.053		
Foot Choice				
RT	20.676	.0001*		
PMRT	14.209	.0003*		
MRT	12.676	.001*		
MT	6.666	.011	2.546	.003 *
Interaction (Age X Activity)			1.302	.142

Note - All Probability values were rounded to the nearest .001 unless otherwise noted.

* Significant at the .05 level for the multivariate F and at the .003 level for the univariate F's.

**RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

Table 4.7 Discriminant function analysis of sixteen reaction time and movement time measures in contributing to performance differences between young males and older males

Variable	Standardized Coefficient
Hand Simple	
Reaction Time	- .002
Premotor Time	- .574
Motor Time	.044
Movement Time	.106
Hand Choice	
Reaction Time	1.408*
Premotor Time	- .615*
Motor Time	- .903
Movement Time	.036
Foot Simple	
Reaction Time	-4.215
Premotor Time	2.657
Motor Time	1.823
Movement Time	- .561
Foot Choice	
Reaction Time	2.251*
Premotor Time	-1.210*
Motor Time	- .010*
Movement Time	.413

Note - The magnitude of the coefficient indicates its contribution to between-group variation.

* Denotes those variables whose univariate F-values were significant in Table 4.6.

When the youngest and oldest age groups were compared via the four separate analyses (reaction time, premotor time, motor time and movement time), significant differences were found for the reaction time (multivariate F = 6.996, P less than .001), premotor time (multivariate F = 4.694, P less than .002) and motor time (multivariate F = 4.056, P less than .004) measures, but not for the movement time (multivariate F = 1.879, P less than .119) variables (Table 4.8). In addition, there were no interaction effects. Among the univariate F's for reaction time, the ones for hand choice reaction time (F = 10.125, P less than .002) and foot choice reaction time (F = 20.676, P less than .0001) were significant at the .012 level and contributed most to the age difference. Of these two, foot choice reaction time performance exerted the most influence toward the difference as evidenced by the standardized discriminant function coefficient (Table 4.9). The premotor components for hand choice reaction time (F = 10.585, P less than .002) and for foot choice reaction time (F = 14.209, P less than .0003) also contributed significantly to the age group differences. In this case, both performance variables contributed nearly equally to the age difference. Only the motor time component for choice foot reaction time was significant (F = 12.676, P less than .001) in contributing toward the age difference between the younger and older age groups on the basis of motor time performance.

There was complete agreement between the results from both the sixteen variable and the four variable analysis with regard to the individual variables responsible for the differences between the young and older groups. The five variables most responsible for the age differences were hand and foot choice reaction time, hand and foot choice premotor time, and foot choice motor time. None of the variables associated with simple hand and simple foot reaction time were significant. These results, when considered in

Table 4.8 Planned comparison test between young males and older males on each set of four measures of reaction time, premotor time, motor time and movement time

	Univariate		Multivariate	
	F	P	F	P
Reaction Time				
Hand Simple	1.816	.180		
Hand Choice	10.125	.002*		
Foot Simple	4.334	.040		
Foot Choice	20.676	.0001*	6.996	.001*
Interaction (Age by Activity)			1.853	.124
Premotor Time				
Hand Simple	1.692	.196		
Hand Choice	10.585	.002*		
Foot Simple	5.164	.025		
Foot Choice	14.209	.0003*	4.694	.002*
Interaction (Age by Activity)			1.211	.310
Motor Time				
Hand Simple	0.681	.411		
Hand Choice	0.233	.631		
Foot Simple	1.650	.202		
Foot Choice	12.676	.001*	4.056	.004*
Interaction (Age by Activity			0.566	.688
Movement Time				
Hand Simple	5.108	.026		
Hand Choice	4.606	.034		
Foot Simple	3.827	.053		
Foot Choice	6.666	.011	1.879	.119
Interaction (Age by Activity)			0.868	.485

Note - All Probability values were rounded to the nearest .001 unless otherwise noted.

* Significant at the .05 level for the multivariate F's and at the .012 level for the univariate F's.

Table 4.9 Discriminant function analysis applied to each set of four measures of reaction time, premotor time, motor time and movement time for young males and older males

Variable	Standardized Coefficient
Reaction Time	
Hand Simple	- .532
Hand Choice	.461*
Foot Simple	- .488
Foot Choice	1.237*
Premotor Time	
Hand Simple	.570
Hand Choice	- .711*
Foot Simple	- .074
Foot Choice	- .704*
Motor Time	
Hand Simple	.223
Hand Choice	- .344
Foot Simple	- .628
Foot Choice	1.368*
Movement Time	
Hand Simple	- .342
Hand Choice	- .189
Foot Simple	.646
Foot Choice	-1.109

* Denotes those variables whose univariate F-values were significant in Table 4.8.

conjunction with the mean performance values on each of the variables (Tables 4.1 and 4.2), indicate that young males perform better than older males on reaction time tasks involving the hand and foot, particularly those tasks which require a decision on choice to be made.

The second contrast, comparing the middle age males to the older age males, failed to yield significant results when all sixteen variables were analyzed at once (Table 4.10). The multivariate F value of 1.484 was not of sufficient magnitude to meet the .05 criterion for significance. Therefore, no further analyses were conducted.

However, when separate analyses were performed on the four sets of four dependent variables (i.e., reaction time, premotor time, motor time and movement time), some differences between the middle age and older age groups were detected (Table 4.11). The multivariate F values on three of the four analyses were significant. These included reaction time (multivariate F = 2.661, P less than .036), motor time (multivariate F = 2.925, P less than .024) and movement time (multivariate F = 4.310, P less than .003). No significant interaction effects were detected in any of the analyses.

Three of the measures for reaction time had significant univariate F values (hand simple, hand choice and foot choice). The fourth measure, foot simple reaction time, approached significance. The most powerful variable contributing to reaction time performance differences was foot choice reaction time followed by hand simple and hand choice reaction time in descending order (Table 4.12). Three movement time variables also contributed significantly to the age effect. These included hand simple, hand choice and foot choice movement time. Discriminant function analysis identified hand choice movement time as the most powerful in denoting the age difference. Foot choice and hand simple movement time also exerted strong influences. It should be noted that the P value for foot simple reaction time (.013) failed to meet the criterion value of .012 by a mere .001 (Table 4.11).

Table 4.10 Planned comparison test between middle age males and older males on sixteen measures of reaction time and movement time

Variable	Univariate F	Univariate P	Multivariate F	Multivariate P
Hand Simple				
RT*	7.404	.008		
PMRT	3.942	.049		
MRT	6.381	.013		
MT	6.920	.010		
Hand Choice				
RT	7.547	.007		
PMRT	4.428	.038		
MRT	4.415	.038		
MT	10.030	.002		
Foot Simple				
RT	5.999	.016		
PMRT	4.786	.031		
MRT	3.915	.050		
MT	6.329	.013		
Foot Choice				
RT	9.434	.003		
PMRT	4.660	.033		
MRT	9.173	.003		
MT	12.221	.0007	1.484	.121
Interaction (Age by Activity)			1.43	.143

Note - All Probability values were rounded to the nearest .001 unless otherwise noted.

*RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

Table 4.11 Planned comparison test between middle age males and older males on each set of four measures of reaction time, premotor time, motor time and movement time

Variable	Univariate F	Univariate P	Multivariate F	Multivariate P
Reaction Time				
Hand Simple	7.404	.008*		
Hand Choice	7.547	.007*		
Foot Simple	5.999	.016		
Foot Choice	9.434	.003*	2.661	.036*
Interaction (Age by Activity)			1.154	.335
Premotor Time				
Hand Simple	3.942	.049		
Hand Choice	4.428	.038		
Foot Simple	4.786	.031		
Foot Choice	4.660	.033	1.671	.162
Interaction (Age by Activity)			2.158	.078
Motor Time				
Hand Simple	6.381	.013		
Hand Choice	4.415	.038		
Foot Simple	3.915	.050		
Foot Choice	9.173	.003*	2.925	.024*
Interaction (Age by Activity)			1.091	.365
Movement Time				
Hand Simple	6.920	.010*		
Hand Choice	10.030	.002*		
Foot Simple	6.329	.013		
Foot Choice	12.221	.0007*	4.310	.003*
Interaction (Age by Activity)			0.793	.532

Note - All Probability values were rounded to the nearest .001.

* Significant at the .05 level for multivariate F's and at the .012 level for univariate F's.

Table 4.12 Discriminant function analysis applied to each set of four measures of reaction time, premotor time, motor time and movement time for middle age males and older males

Variable	Standardized Coefficient
Reaction Time	
Hand Simple	- .328*
Hand Choice	- .189*
Foot Simple	.056
Foot Choice	- .661*
Premotor Time	
Hand Simple	- .113
Hand Choice	- .434
Foot Simple	- .466
Foot Choice	- .214
Motor Time	
Hand Simple	- .561˙
Hand Choice	.061
Foot Simple	.225
Foot Choice	- .866*
Movement Time	
Hand Simple	1.000*
Hand Choice	-1.332*
Foot Simple	.586
Foot Choice	-1.172*

*Denotes those variables whose univariate F values were significant in Table 4.11.

Only one of the four motor time variables, foot choice, contributed significantly to the performance difference between middle age and older age males. However, the F value for hand simple motor time was nearly significant (univariate F = 6.381, P less than .013).

Middle age men performed significantly different from older age men in reaction time, motor time and movement time, but not in premotor time. However, these differences were only detected when the variables were clustered and analyzed separately. In each instance where differences were found, the middle age males performed better than the older males.

Activity and Reaction Time. The third hypothesis, that there is less deterioration in reaction time and movement time responses with advancing age in individuals who engage in a regular program of physical activity than in individuals who are currently less active or were formerly active, also was tested by MANOVA procedures. The performances of the two activity groups, "active" and "less active," on the sixteen reaction time and movement time variables were analyzed by the two approaches used in the previous section--inclusion of all sixteen measures in one analysis and division of the sixteen measures into four groups for separate analysis. An alpha level of .05 was chosen as the criterion for significance.

Simultaneous inclusion of all sixteen measures of reaction and movement time failed to detect an activity effect. The multivariate F value of 1.616 had a P value of .078 (Table 4.13). Thus, this outcome does not support the third hypothesis. However, the limitation of the procedures for classifying the subjects into activity groups warrants that final judgment concerning the effect of activity on reaction time and movement time be reserved.

The results of the four separate MANOVA procedures also failed to support the third hypothesis. None of the multivariate F values for reaction time (F = .660, P less than .621), premotor time (F = 1.467, P less than .217), motor time (F = 1.428, P less than .229), and movement time (F = 1.671, P less than .162) were significant

Table 4.13 Multivariate analysis of variance for activity effects on sixteen measures of reaction time and movement time

Variable	Univariate F	Univariate P	Multivariate F	Multivariate P
Hand Simple				
RT*	2.137	.147		
PMRT	3.673	.058		
MRT	0.098	.755		
MT	0.193	.661		
Hand Choice				
RT	0.445	.506		
PMRT	0.937	.335		
MRT	0.227	.635		
MT	0.119	.731		
Foot Simple				
RT	0.794	.375		
PMRT	0.060	.807		
MRT	2.640	.107		
MT	0.160	.690		
Foot Choice				
RT	0.776	.380		
PMRT	0.004	.947		
MRT	3.988	.048		
MT	0.888	.348	1.616	.078
Interaction (Age by Activity)			1.302	.142

Note - All Probability values were rounded to the nearest .001.

*RT = Reaction time

PMRT = Premotor reaction time

MRT = Motor reaction time

MT = Movement time

Table 4.14 Multivariate analysis of variance for activity effect on each set of four measures of reaction time, premotor time, motor time and movement time

Variable	Univariate F	Univariate P	Multivariate F	Multivariate P
Reaction Time				
Hand Simple	2.137	.147		
Hand Choice	0.445	.506		
Foot Simple	0.794	.375		
Foot Choice	0.776	.380	0.660	.621
Interaction (Age by Activity)			1.480	.166
Premotor Time				
Hand Simple	3.673	.058		
Hand Choice	0.937	.335		
Foot Simple	0.060	.807		
Foot Choice	0.004	.947	1.467	.217
Interaction (Age by Activity)			1.654	.111
Motor Time				
Hand Simple	0.098	.755		
Hand Choice	0.227	.635		
Foot Simple	2.640	.107		
Foot Choice	3.988	.048	1.428	.229
Interaction (Age by Activity)			0.827	.580
Movement Time				
Hand Simple	0.193	.661		
Hand Choice	0.119	.731		
Foot Simple	0.160	.690		
Foot Choice	0.880	.348	1.671	.162
Interaction (Age by Activity)			0.825	.581

Note - All Probability values were rounded to the nearest .001.

(Table 4.14). These results indicate that under the criteria used for classifying the subjects into active and less active groups, activity level had little influence on the reaction time and movement time performance of the subjects participating in this study.

Discussion

The purpose of the study was to compare the fractionated reaction time and movement time performances of male subjects across various age and physical activity levels. This discussion will focus on a comparison of the results of this study with previous findings in terms of: (1) total reaction time and movement time and (2) fractionated reaction time.

Total Reaction Time and Movement Time

The results of this study support the generalization that age is a significant factor in the deterioration of reaction time and movement time performance. The three age groups of young males, middle age males, and older males were significantly different from each other in total reaction time and movement time of the hand and foot, including both simple and choice reaction time.

The literature generally supports the notion that reaction time improves with age until maturity is reached and subsequently deteriorates with old age (Bellis, 1933; Pierson, 1957; Mendryk, 1960; Hodgkins, 1962). The current investigation showed age differences for both simple and choice reaction time of the hand and foot. Young males were significantly faster than older males in hand choice reaction time and foot choice reaction time, but not in hand simple reaction time and foot simple reaction time. Middle age males were significantly faster than older males in hand simple reaction time, hand choice reaction time, and foot choice reaction time. Middle age males performed as slow as older males in foot simple reaction time. A plausible explanation for the failure to obtain age differences between young males and older males in hand and foot simple reaction time; and, also between middle age males and older males in foot simple reaction time was the lack of perceptual difficulty in the task performed. These results coincide with those obtained in the studies by Birren and Botwinick (1955), Simon (1968), Elliot (1970), Surwillo (1973), Birren (1974), and Gaylord and Marsh (1975), all of whom found that speed of response is also a function of perceptual difficulty. Thus tasks with little perceptual difficulty place few demands on the central nervous system thereby minimizing the effects of age on performance.

The results of the present study clearly indicated some age differences for movement time measures. These results pertain to movement time associated with hand simple reaction time, hand choice reaction time, foot simple reaction time and foot choice reaction time. Although the young males did not move faster than the older males on the four variables of movement time performance (Table 4.8), the middle age males did move significantly faster than the older males (Table 4.11). These differences were present for three of the four movement time performances when analyzed by MANOVA procedures that included only the four movement time variables. However, in the sixteen variable MANOVA, the univariate F's for movement time were not interpreted since the multivariate F value obtained was not significant. These results are in partial agreement with the findings of Bellis (1933) and Pierson (1977). Why the movement time of the young subjects was as slow as that of the older subjects is not known. Perhaps some undetected bias was operating in the process of obtaining the young male volunteers.

The results of this study failed to show a significant difference between active and less active males on any of the four total reaction time measures. Active males also did not move faster than the less active males on any of the movement time variables. These results are contrary to the findings of other investigators (Botwinick & Thompson, 1968; Spirduso, 1975; Spirduso & Clifford, 1978; Clarkson, 1978), who found that elderly people exhibiting an active life style react and move significantly faster than non-active people. A possible explanation for the lack of a significant activity effect might be the failure to include truly sedentary males in this investigation. The lack of extreme activity groups may have failed to provide the range of differences in activity life style necessary to detect differences in performance. It is also possible that the activities engaged in by a majority of the active subjects, i.e., jogging and swimming, do not require fast reactions and therefore the reaction time performance of these active subjects would not be significantly different from those of their less active peers. Even so, the activity main effect approached significance (P less than .078) in the current investigation, thereby lending some support to this interpretation.

Fractionated Reaction Time

Age-related lengthening of reaction time due to a change in the quality of central nervous system processing rather than in the speed of muscular contraction has been reported previously (Birren & Botwinick, 1955; Weiss, 1965, Kroll & Clarkson, 1977; Clarkson, 1978). The results obtained in the present investigation are in general agreement with the findings of these earlier studies.

A significant difference was found between the three age groups in premotor times. Young males, middle age males, and older males were significantly different from each other in the premotor time components of hand choice, foot simple and foot choice reaction time when the four premotor time variables were analyzed alone. However, when the sixteen variable MANOVA was applied, the three groups were not significantly different from each other in the premotor time component of foot simple reaction time. In both the four and sixteen variable analyses, the young males were significantly different from the older males in premotor times associated with hand choice and foot choice reaction time but were not in premotor times associated with hand simple and foot simple reaction time. Middle age males were not significantly different from older males on any of the premotor time variables.

The results of this investigation revealed that the three age groups were significantly different from each other only in motor time associated with foot choice reaction time in both the four variable and the sixteen variable MANOVA analyses. Young males, middle age males and older males were not significantly different from each other on the rest of the motor time variables. This part of the results partially agrees with the findings of Botwinick and Thompson (1966), who found that elderly subjects are slower than young subjects in both premotor time and motor time components.

The results of the fractionated reaction time analyses also showed that active males were not significantly different from less active males on either the premotor or the motor time components in both the four variable MANOVA and the sixteen variable MANOVA procedures. These results are in contradiction with the findings of Clarkson (1978). Again, the lack of a difference may be explained by the failure to include sedentary males in the research design or by the type of activity engaged in by the active subjects.

CHAPTER V

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

The purpose of this investigation was to compare the fractionated reaction time and movement time performances of male subjects across various age and physical activity levels. More specifically, this study was designed to compare the fractionated simple reaction time of the hand and foot, the fractionated choice reaction time of the hand and foot, as well as movement time of the hand and foot for 120 male volunteers from the University community at Michigan State. The subjects were divided into six groups according to age and level of physical activity. Two groups included men 20 to 30 years of age, two middle age groups were comprised of men ranging in age from 40 to 51 years and two older age groups were made up of men between 58 and 79 years of age. Three practice trials were given to permit the subjects to become familiar with the equipment and procedures. Following the practice trials, each subject completed a total of 48 trials including 12 hand simple, 12 hand choice, 12 foot simple, and 12 foot choice reaction time trials.

The data were analyzed by multivariate analysis of variance procedures to detect any significant difference in the performance of the three age groups or the two activity groups on total reaction time, premotor time, motor time, and movement time. Analysis of the data indicated that age generally was a significant factor in total reaction time (i.e., hand simple, hand choice, foot simple and foot choice reaction time), in premotor time, in motor time associated with foot choice reaction time and in movement time performance.

Young males were significantly faster than older males in hand choice reaction time and foot choice reaction time, but not different in hand or foot simple reaction time. Middle age males also were faster than older males in hand simple reaction time, hand choice reaction time, and foot choice reaction time, but not in foot simple reaction time.

Young males were significantly faster than older males in the premotor times associated with hand choice reaction time and foot choice reaction time, but not in the premotor times associated with hand simple and foot simple reaction time. The two groups of middle age males and older males were not significantly different from each other on any of the premotor times.

Young males were significantly faster than older males only in motor time associated with foot choice reaction time. Middle age males also were significantly faster than older males but only on motor time associated with foot choice reaction time.

Young males were not significantly faster than older males in movement time. However, middle age males were significantly faster than older males in movement time performance associated with hand simple, hand choice and foot choice reaction time.

Active males and less active males were not significantly different from each other in terms of (a) total reaction time (i.e., hand simple, hand choice, foot simple or foot choice reaction time); (b) premotor times; (c) motor times; or, (d) movement time. The same results were obtained when all sixteen reaction time variables were included in one analysis when they were analyzed in four sets of related variables.

Conclusions

The following conclusions are drawn from the results of this study within the limitations outlined in Chapter One:

1. The premotor time component is longer than the motor time component of reaction time.
2. Hand reaction time is faster than foot reaction time.
3. Most of the difference between simple reaction time and choice reaction time performance is in the premotor time component of reaction time.
4. Age is a significant factor in the (total) reaction time of the hand and foot. It influences performance on both simple and choice reaction time tasks.
5. Age is a significant factor in premotor time associated with hand simple, hand choice, foot simple and foot choice reaction time.
6. Age is a significant factor only in motor time associated with foot choice reaction time.
7. Age is a significant factor in movement time associated with hand simple, hand choice, foot simple and foot choice reaction time.

8. Activity is not a significant factor in the (total) reaction time of the hand and foot, including simple and choice reaction time tasks.
9. Activity is not a significant factor for the premotor time component of hand simple, hand choice, foot simple and foot choice reaction time.
10. Activity is not a significant factor for the motor time component of hand simple, hand choice, foot simple and foot choice reaction time.
11. Activity is not a significant factor in the movement time responses associated with hand simple, hand choice, foot simple and foot choice reaction time.
12. No interaction effects occurred between age and activity for any of the dependent variables mentioned above.

Recommendations

The following suggestions are offered for future research on the problem investigated in this study:

1. The subjects in the present study were volunteers from the university community at Michigan State. It is recommended that a larger number of subjects in the various age groups be included who are selected on a random basis.
2. Future studies should include both male and female subjects.
3. The effect of the length of the pre-stimulus interval and the nature of the pre-stimulus warning signal on fractionated reaction time and movement time should be examined.

4. Since categorizing the subjects into active and less active groups on the basis of self-reporting activity history of the subject has some serious limitations, replication of the study with active males whose activity history is determined from sources other than a self-reporting instrument is recommended.

5. Active subjects in this study engaged in different sports activities. It is recommended that comparisons be made between active individuals who participate in endurance activities and those who engage in activities that require rapid decisions.

6. Lack of interest and motivation resulted in sedentary individuals declining to participate in this study. More persistent efforts should be made in future investigation to include such persons.

7. For the purpose of discovering the residual effect of sports participation on fractionated reaction time and movement time performance, a clearly defined group of formerly active subjects should be included in future investigations.

8. In this study, the electrodes were attached to the "hamstring" muscles for all the foot reaction time tasks. The possibility exists that electrodes should also be attached to other muscles for the foot choice reaction time and movement time tasks since the foot is required to be moved in any of three different directions (forward,

sideward or backward). It is recommended that in future studies the electrodes be attached to different muscles of thigh to determine if more than one source of input for these movements is necessary.

9. Since the subjects were tested between 9:00 A.M. and 6:00 P.M., the time of testing should be used as covariate in future studies of reaction time where time of day may be a factor in performance.

APPENDIX A

APPENDIX A

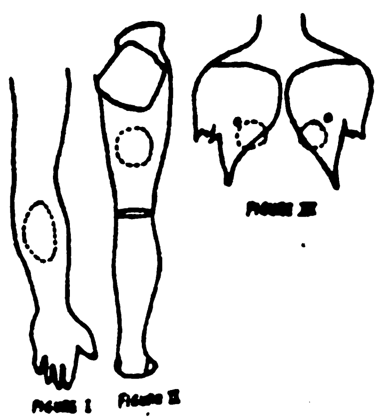
Dear

Thank you for agreeing to participate in the reaction time and movement time study sponsored by the Department of Health, Physical Education and Recreation. Your cooperation is greatly appreciated. The following information is provided to help reduce your time in the laboratory.

Dress - Please bring gym shorts or swimming trunks and rubber soled shoes for the testing.

Shaving - To expedite the placement of surface electrode you are requested to shave the following body surfaces:

1. Upper posterior half of the forearm of the dominant hand (Figure I).
2. Middle part of the posterior thigh of the dominant leg (Figure II).
3. Chest over the sixth rib (Figure III).



Testing Procedures

Hand Reaction Time. You will sit on a chair with the dominant hand over the releasing reaction time button. Adjust your position until you can comfortably touch each of the hand Microswitches. The signal lights will be located in front of you. Place the index finger of your dominant hand on the reaction time button. At the stimulus of light on choice reaction time task, move your hand and your arm in a forward direction with the greatest possible speed from the reaction time button to the appropriate Microswitch. For the simple reaction time test, move your hand to touch the middle Microswitch.

Foot Reaction Time. You will stand in position with dominant foot on the reaction time button. Adjust your position so that you can comfortably touch each of the three foot Microswitches. The signal light will be located in front of you. Place your dominant foot on the reaction time button. At the stimulus of light on the choice reaction time test move your foot in a forward, sideward, or backward direction with the greatest possible speed from foot reaction time button to the appropriate foot switch. For the simple reaction time task you will move your foot in a forward direction to touch the Microswitch.

For both the hand reaction time and foot reaction time tasks, a warning signal (buzzer) will be given to you prior to each trial. The time between the warning signal and the stimulus will be randomly varied from half of a second to three seconds. Three practice trials will be given to permit you to become familiar with the equipment and procedures. Following the practice period, you will be given 12 consecutive trials on each of the four tests. The order for hand reaction time and foot reaction time testing will be randomly determined. The twelve trials for choice reaction time will follow the twelve simple reaction time trials. Thus a total of 48 trials will be taken (simple reaction time - hand and foot; and, choice reaction time - hand and foot). The estimated time required for each subject to be tested is 1 to 1½ hours.

You also will be asked to complete a brief biographical form so that appropriate demographical information and your activity history can be obtained for analysis of the data.

Your appointment for testing is on ______________ (day), ______________ (date)

______________ (time) AM PM.

If this appointment is not convenient for you, please call for a reappointment.

APPENDIX B

APPENDIX B

MICHIGAN STATE UNIVERSITY
Department of Health, Physical Education and Recreation

Reaction Time Study
Subject History

NAME____ SUBJECT NUMBER_________
(last) (first)

TODAY'S DATE____________________ BIRTHDATE ________________________
(month) (day) (year) (month) (day) (year)

AGE ______________ OCCUPATION____________________________________
(year) (month)

What are the physical demands of your occupation? (Hours of standing, walking, physical labor, etc.)______________________________________

____

____

Circle the age group appropriate for you: 20-30 40-50 60 and older

Identify the activity group that best describes you and complete the information requested.

Active Group: Men who have been physically active most of their lives and who currently run or swim thirty (30) minutes or more at least 3 times per week.

1. For how many years have you been involved in this swimming and/or running program? ________years

   Briefly describe your weekly activity schedule.___________

   ____

2. In addition to the above, have you engaged in a regular physical activity program during the past 5 years?
   ____yes ____no

3. If yes, briefly explain the nature, extent (intensity) and duration of participation in this program.________________

____

4. In the space below indicate your involvement in organized physical activity programs up until about five years ago. Include your involvement in high school and college sports programs.____

____

____

____

<u>Formerly Active Group</u>: Men who were physically active during their younger years, but have not been involved in vigorous physical activity programs for at least 5 years (20-30 age group), 10 years (40-50 age group) or 20 years (60 and older age group).

5. For how many years were you actively involved in vigorous physical activity? _________years

6. In the space below, please describe the nature, extent (intensity) and duration of participation in such activity.

____

____

____

____

<u>Non-active Group</u>: Men who do not exercise regularly and who never participated in organized physical activities on a regular basis.

7. Did you ever participate in an organized program of physical activity (other than required physical education classes in school) that was one or more years in duration? _____yes _____no

(If yes, you should be completing one of the previous sections).

8. Briefly describe the nature, duration and extent (intensity) of your involvement, if any, in organized physical activity programs that was less than one year in duration.

____

____

____

____

9. Have you regularly engaged in physical activity on a recreational (free play) basis during your lifetime?

____yes ____no

10. If yes, briefly describe the nature, duration and extent (intensity) of such participation.

____

____

____

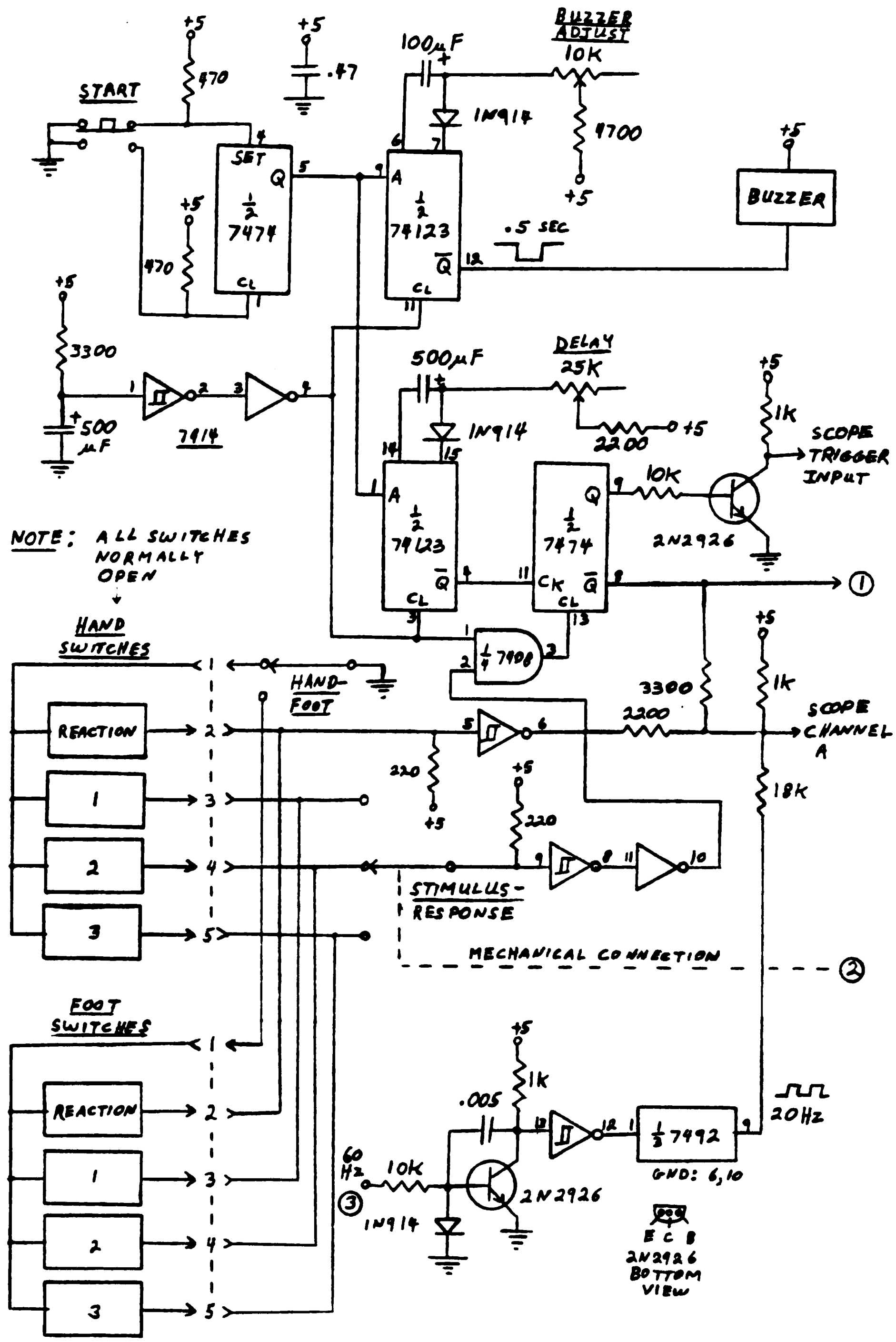
____

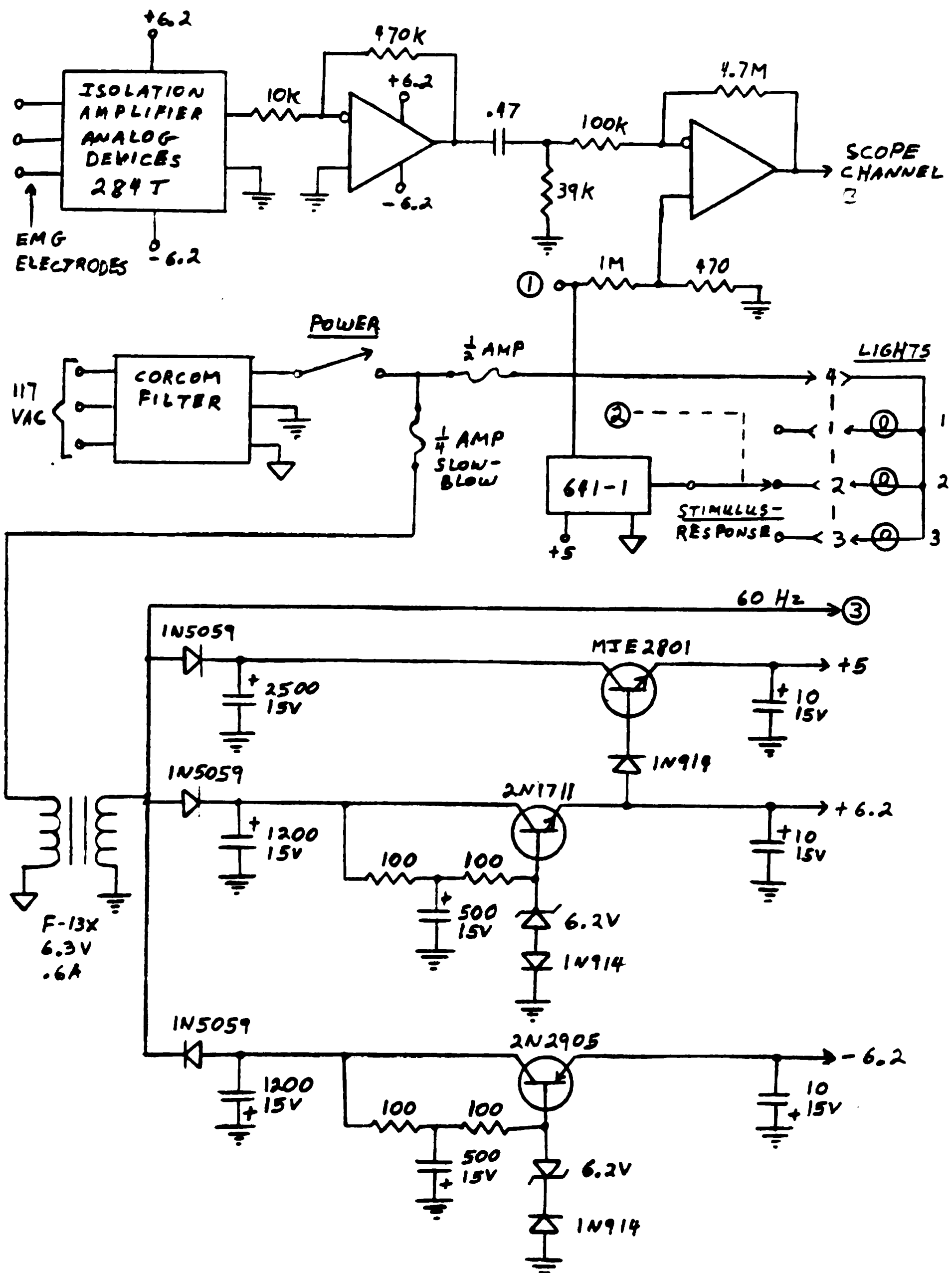
THANK YOU FOR YOUR COOPERATION!

APPENDIX C

APPENDIX C

REACTION TIME CONTROL UNIT





+6.2
ISOLATION AMPLIFIER ANALOG DEVICES 284T
EMG ELECTRODES
-6.2
10K
470K
+6.2
-6.2
.47
100k
39K
4.7M
SCOPE CHANNEL
1M
470
①
POWER
CORCOM FILTER
117 VAC
1/2 AMP
1/4 AMP SLOW-BLOW
LIGHTS
②
641-1
+5
STIMULUS-RESPONSE
60 Hz
③
1N5059
2500 15V
MJE2801
+5
10 15V
1N914
1N5059
1200 15V
2N1711
+6.2
10 15V
100
100
500 15V
6.2V
1N914
F-13X 6.3V .6A
1N5059
2N2905
-6.2
1200 15V
10 15V
100
100
500 15V
6.2V
1N914

BIBLIOGRAPHY

Bibliography

Abrahams, J.P. and Birren, J.E. Reaction Time as a Function of Age and Behavioral Predisposition to Coronary Heart Disease. J. of Gerontology, 1973, Vol. 28, pp. 471-478.

Beagley, H.A. and Sheldrark, J.B. Differences n Brainstem Response Latency with Age and Sex. British J. of Audiology, 1978, Vol. 12, pp. 69-77.

Bellis, C.J. Reaction Time and Chronological Age. Proceedings of the Society for Experimental Biology and Medicine, 1933, Vol. 36, pp. 801-803.

Birren, J.E. and Botwinick, J. Speed of Response as a Function of Perceptual Difficulty and Age. J. of Gerontology, 1955, Vol. 10, pp. 433-436.

Birren, J.E. and Spieth, W. Age, Response Speed and Cardiovascular Functions. J. of Gerontology, 1962, Vol. 17, pp. 390-391.

Birren, J.E. Translations in Gerontology--From Lab to Life: Psychophysiology and Speed of Response. Am. Psychologist, 1974, Vol. 29, pp. 808-815.

Botwinick, J. Sensory-Set Factors in Age Differences in Reaction Time J. of Genetic Psych. 1971, Vol. 119, pp. 241-249.

Botwinick, J. Theories of Antecedent Conditions of Speed of Response. In A.T. Welford and J.E. Birren (Editors), Behavior, Aging, and Nervous System. Charles C. Thomas, Springfield, Ill., 1965, pp. 67-87.

Botwinick, J. and Storandt, M. Age Differences in Reaction Time as a Function of Experience, Stimulus Intensity and Preparatory Interval. J. of Genetic Psych. 1973, Vol. 123, pp. 209-217.

Botwinick,J. and Storandt, M. Cardiovascular Status, Depressive Effect, and Other Factors in Reaction Time. J. of Gerontology, 1974, Vol. 29, pp. 543-548.

Botwinick, J. and Thompson, L.W. Components of Reaction Time in Relation to Age and Sex. J. of Genetic Psych., 1966, Vol. 108, pp. 175-183.

Botwinick, J. and Thompson, L.W. Premotor and Motor Components of Reaction Time. J. of Ex. Psych., 1966, Vol. 71, pp. 9-15.

Botwinick, J. and Thompson, L.W. A Research Note on Individual Differences in Reaction Time in Relation to Age. J. of Genetic Psych., 1968, Vol. 112, pp. 73-75.

Botwinick, J. and Thompson, L.W. Age Differences in Reaction Time: An Artifact? Gerontologist, 1968, Vol. 8, pp. 25-28.

Botwinick, J. and Thompson, L.W. Cardiac Functioning and Reaction Time in Relation to Age. J. of Genetic Psych., 1971, Vol. 119, pp. 127-132.

Carron, A.V. and Bailey, D.A. A Longitudinal Examination of Speed of Reaction and Speed of Movement in Young Boys 7 to 13 Years. Human Biology, 1973, Vol. 45, pp. 663-681.

Clarkson, P.M. The Relationship of Age and Level of Physical Activity with the Fractionated Components of Patellar Reflex Time. J. of Gerontology, 1978, Vol. 33, pp. 650-656.

Crews, T.R. and Meadors, W.J. Analysis of Reaction Time, Speed and Body Composition of College Football Players. J. of Sport Med., Vol. 18, pp. 169-74.

Eckert, H.M. and Eichorn, D.H. Developmental Variability in Reaction Time. Child Development, 1977, Vol. 48, pp. 452-458.

Elliott, R. Simple Reaction Time: Effects Associated with Age, Preparatory Interval, Incentive-Shift, and Mode of Presentation. J. of Ex. Child Psych., 1970, Vol. 9, pp. 86-107.

Engel, B.T., Thorne, P.R., and Quilter, R.E. On the Relationships Among Sex, Age, Response Mode, Cardiac Cycle Phase, Breathing Cycle Phase, and Reaction Time. J. of Gerontology, 1972, Vol. 27, pp. 456-460.

Finn, J.D. Multivariance: Univariate and Multivariate Analysis of Variance, Covariance, Regression and Repeated Measures. National Educational Resources, Chicago, Ill., 1978.

Fozard, J.L., Thomas, J.C., and Waugh, N.C. Effect of Age and Frequency of Stimulus Repetitions on Two-Choice Reaction Time. J. of Gerontology, 1976, Vol. 31, pp. 556-563.

Fulton, C.D. and Hubbard, A.W. Effect of Puberty on Reaction and Movement Times. Research Quarterly, 1975, Vol. 46, pp. 335-344.

Gaylord, S.A. and Marsh, G.R. Age Differences in the Speed of a Spatial Cognitive Process. J. of Gerontology, 1975, Vol. 30, pp. 674-678.

Goodenough, F.L. The Development of the Reactive Process from Early Childhood to Maturity. J. of Ex. Psych., 1935, Vol. 18, pp. 431-450.

Gore, I.Y. Physical Activity and Aging - A Survey of Soviet Literature, Geront. Clin., Vol. 14, pp. 65-69.

Hodgkins, J. Influence of Age on the Speed of Reaction and Movement in Females. J. of Gerontology, 1962, Vol. 17, pp. 385-89.

Jones, H.E. Reaction Time and Motor Development. Am. J. of Psychology, 1937, Vol. 50, pp. 181-194.

Jordan, T.C. and Rabbitt, M.A. Response Times to Stimuli of Increasing Complexity as a Function of Aging. Br. J. of Psych., 1977, Vol. 68, pp. 189-201.

Kroll, W. Fractionated Reaction and Reflex Time Before and After Fatiguing Isometric Exercise. Medicine and Science in Sports, 1974, Vol. 6, pp. 260-266.

Kroll, W. and Clarkson, P.M. Fractionated Reflex Time, Resisted and Unresisted Fractionated Time Under Normal and Fatigued Conditions. Psychology of Motor Behavior and Sports, Urbana, Illinois. Human Kinetics, 1977, pp. 108-129.

Lagasse, P.P. and Hayes, K.C. Premotor and Motor Reaction Time as a Function of Movement Extent. J. of Motor Behavior, 1973, Vol. 5, pp. 25-32.

Loveless, N.E. and Sanford, A.J. Effects of Age on the Contingent Negative Variation and Preparatory Set in a Reaction Time Task. J. of Gerontology, 1974, Vol. 29, pp. 52-63.

Mendryk, S. Reaction Time, Movement Time, and Task Specificity Relationships at Age 12, 22, and 48 Years. Research Quarterly, 1960, Vol. 1, pp. 259-268.

Morris, H. Effects of Practice and Set Upon Reaction Time and Its Fractionated Components. Psychology of Motor Behavior and Sports, 1976, Vol. 1, pp. 259-268.

Nebes, R.D. Vocal Versus Manual Response as a Determinant of Age Difference in Simple Reaction Time. J. of Gerontology, 1978, Vol. 33, pp. 884-889.

Obrist, P.A., Howard, J.L., Sutterer, J.R., Hennis, R.S., and Morrell, D.J. J. of Ex. Child Psych., 1973, Vol. 16, See Elliott, R., oo, 346-362.

Panek, P.E., Barrett, G.V., and Alexander, R.A. Age Differences in Perceptual Style, Selective Attention, and Perceptual-Motor Reaction Time. Exp. Aging Research, 1978, Vol. 4, pp. 377-387.

Philip, B.R. Reaction-Times of Children. Am. J. of Psychology, 1934, Vol. 46, pp. 379-396.

Pierson, W.R. A Study of Reaction Time and Movement Time in Relation to Chronological Age. Ph.D. Thesis. Michigan State University, 1957.

Reynolds, H.L. The Effects of Augmented Levels of Stress on Reaction Time in the Peripheral Visual Field. Research Quarterly, 1976, Vol. 47, pp. 768-775.

Rotella, R.J. and Bunker, L.K. Field Dependence and Reaction Time in Senior Tennis Players. Perceptual and Motor Skills, 1978, Vol. 46, pp. 585-586.

Salthouse, T.A. Speed and Age: Multiple Parts of Age Decline. Ex. Aging Research, 1976, Vol. 2, pp. 349-359.

Santa Maria, D.L. Premotor and Motor Reaction Time Differences Associated with Stretching of the Hamstring Muscles. J. of Motor Behavior, 1970, Vol. 11, pp. 163-173.

Schmidt, R.A. and Stull, G.A. Premotor and Motor Reaction Time as a Function of Preliminary Muscular Tension. J. of Motor Behavior, 1970, Vol. 11, pp. 96-110.

Simon, J.R. Signal Processing Time as a Function of Aging. J. of Ex. Psych., 1968, Vol. 78, pp. 76-80.

Sherwood, D.E. and Selder, D.J. Cardiorespiratory Health, Reaction Time and Aging. Medicine and Science in Sports, 1979, Vol. 11, pp. 186-189.

Spirduso, W.W. Reaction and Movement Time as a Function of Age and Physical Activity Level. J. of Gerontology, 1975, Vol. 30, pp. 435-440.

Spirduso, W.W. and Clifford, P. Replication of Age and Physical Activity Effects on Reaction and Movement Time. J. of Gerontology, 1978, Vol. 33, pp. 26-30.

Surwillo, W.W. Choice Reaction Time and Speed of Information Processing in Old Age. Perceptual and Motor Skills, 1973, Vol. 36, pp. 321-322.

Surwillo, W.W. Human Reaction Time and Period of the EEG Relation to Development. Psychophysiology, 1971, Vol. 8, pp. 468-482.

Surwillo, W.W. Motor Time and Reaction-Time Changes in Children. Perceptual and Motor Skills, 1972, Vol. 35, pp. 210.

Surwillo, W.W. and Quilter, R.E. The Influence of Age on Latency Time of Involuntary (Galvanic Skin Reflex) and Voluntary Response. J. of Gerontology, 1965, Vol. 20, pp. 173-176.

Surwillo, W.W. and Quilter, R.E. Vigilance, Age, and Response Time. Am. J. of Psychology, 1964, Vol. 77, pp. 614-620.

Talland, G.A. and Cairnie, J. Aging Effects on Simple, Disjunctive, and Alerted Finger Reaction Time. J. of Gerontology, 1961, Vol. 16, pp. 370-374.

Thompson, L.W. and Botwinick, J. Age Differences in the Relationship Between EEG Arousal, and Reaction Time. J. of Psych., 1968, Vol. 68, pp. 167-172.

Tweit, A.H., Gollinick, P.D., and Hearn, G.R. Effect of Training Program on Total Body Reaction Time of Individuals of Low Fitness. Research Quarterly, 1963, Vol. 34, pp. 508-513.

Waugh, N.C., Fozard, J.L., Talland, G.A., and Erwin, D.E. Effects of Age and Stimulus Repetition on Two-Choice Reaction Time. J. of Gerontology, 1973, Vol. 28, pp. 466-470.

Weiss, A.D. The Locus of Reaction Time Changes with Set, Motivation and Age. J. of Gerontology, 1965, Vol. 20, pp. 60-64.

Wyrick, W. and Duncan, A. Electromyographical Study of Reflex, Premotor, and Simple Reaction Time of Relaxed Muscle to Joint Displacement. J. of Motor Behavior, 1974, Vol. 6, pp. 1-10.