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An analysis of motor coordination in fit versus less fit young adult males

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AN ANALYSIS OF MOTOR COORDINATION IN FIT VERSUS LESS FIT YOUNG ADULT MALES

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

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submitted in partial fulfillment of the requirements for the degree of Master of Science in Exercise and Sport Science at Ithaca College has been approved.

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ABSTRACT

The purpose of this study was to compare the motor coordination components of movement between young adult males who are physically fit versus those who are less fit. Fourteen subjects participated in the study and were divided into two groups – Fit (*M* = 56.6 ml/kg/min, *SD* = 4.6) and Less Fit (*M* = 43.2 ml/kg/min, *SD* = 4.5) – based on maximal oxygen consumption (VO2 max). Each subject underwent two days of testing. The complex motor task involved moving a lever arm horizontally to one of four positions based upon the presentation of the appropriate stimulus. Performance was determined from a number of variables collected, including reaction time, movement kinematics, and movement accuracy. The results of the study indicate that while the Fit and the Less Fit groups were comparable in regards to the accuracy of the movements, the Fit group had a faster movement time and a faster acceleration. For reaction time, the Fit group (*M* = 185 ms) tended to be faster than the Less Fit group (*M* = 239 ms), albeit not statistically significant (p = .0948). The Fit group (*M* = 231 ms) was significantly faster than the Less Fit group (*M* = 285 ms) for movement time (p = .0066) and the Fit group (*M* = 740 arbitrary units) was significantly faster than the Less Fit group (*M* = 530 arbitrary units) for acceleration (p = .0077). The likely source of the differences between groups for both movement time and acceleration is the longer movements. This study suggests that motor coordination benefits from physical fitness are detectable in the young adult population. It may be speculated that regular exercise in young adults may lead to greater motor coordination in accomplishing a motor task.

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DEDICATION

This is dedicated foremost to my wife and best friend, Catherine, for her continued encouragement to complete this thesis. To my beautiful daughter, Fiona, for keeping me going with the never ending smiles and kisses. And to God, for blessing me with a wonderful family who have waited patiently for me to achieve this goal.

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Chapter 1

INTRODUCTION

The ability for an individual to produce purposeful and coordinated movement is dependent upon many interacting factors. Producing coordinated movements involves an individual detecting stimuli or environmental cues, mentally processing this information, selecting an appropriate action, activating the necessary muscle groups, and coordinating the body to perform a fluid motion (Schmidt, 1982). Coordinated movements involve a whole range of human capabilities. These capabilities can be generally grouped as physiological or psychological. Physiological capabilities include neurological factors (e.g., motor unit firing rates), musculoskeletal factors (e.g., muscle strength and size), cardiopulmonary factors (e.g., maximal oxygen consumption), and so forth. Psychological factors include memory, cognition and information processing speed, decision-making skills, perceptual acuity, and emotional control. These psychological factors, as related to the production of coordinated movement, are termed psychomotor factors.

How all these factors specifically contribute to the production of coordinated movements has been a focus of much research, but many questions remain. For instance, considerable research documents that athletes exhibit noticeable differences in motor coordination than non-athletes, such as athletes having decreased reaction times compared with non-athletes (Burley, 1944; Cureton, 1951; Hubbard, 1956; Keller, 1942; Youngen, 1959). It is unclear, however, if this better motor coordination is related to findings that athletes have faster movement-related information processing (Jackson, 1971; Keller, 1942; Kerr & Boucher, 1992; Steitz, 1963), or if it is because athletes have better physiological capabilities, like better aerobic capacity and muscle strength (Youngen, 1959). Certainly both physiological and psychomotor capabilities contribute to an athlete's well developed motor coordination, but the relative contribution of one versus the other remains a topic for debate (Ives & Shelley, 2003).

It is also not known whether the better motor coordination in athletes, especially the psychomotor component, is because of some genetic disposition or is a result of training and practice (Hascelik, Basgoze, Turker, Narman, & Ozker, 1989; Mokhu, Kaur, & Sidhu, 1992). Put differently, athletes improve their reaction time and overall coordination through specific skill-related practice, but does improvement in physical conditioning alone, obtained through general physical training, contribute specifically to better psychomotor capabilities and generally to better motor coordination?

This question has been examined to some extent in the elderly. It is well documented that as a person ages their neurological and musculoskeletal systems deteriorate, resulting in poorer motor performance, including declines in muscle strength and slower reaction time (Booth, Weeden, & Tseng, 1994; Koga & Morant, 1923; Noble, 1978; Schmidt, 1982; Spirduso, 1975). On the other hand, numerous studies have shown that physical activity in the elderly is associated with stronger muscles, faster reaction times, and overall better motor coordination when compared to inactive individuals of the same age group (Clarkson, 1978; Clarkson & Kroll, 1978; Rotella & Bunker, 1978; Smith & Green, 1962; Spirduso, 1975; Spirduso & Clifford, 1978). Some of these improvements in motor coordination may be due to enhanced physiological systems, such as muscle hypertrophy and metabolic changes (Frischknecht, 1998), and some may be due to improved neurological pathways as a result of enhanced blood and oxygen flow to the central nervous system (Doherty, 1993; Doherty, Vandervoort, & Brown, 1993; Dustman et al., 1984; Spirduso, 1982).

Recent evidence from a variety of studies incorporating different measurement techniques has demonstrated that physically active elders have numerous enhancements in brain chemistry and morphology than less fit elders, which may explain the better information processing and faster reaction times in the physically active elders (Colcombe & Kramer, 2003). Young people, like the elderly, experience anatomical and physiological improvements arising out of living a lifestyle with physical activity, but it is unknown if the increased performance in motor coordination experienced by elders as a result of physical fitness holds true for younger adults.

Statement of Purpose

The purpose of this study is to compare the psychomotor components of movement between young adult males who are fit verses those who are less fit based upon cardiovascular capacity. Specifically, the performance on a complex psychomotor task, taking into account reaction time, anticipation timing, limb movement speed, and target accuracy, is compared between young adult male non-athletes to examine the benefits of cardiovascular fitness.

Hypotheses

1. Subjects with a higher level of fitness will exhibit faster reaction time and movement time.
2. Subjects with a higher level of fitness will exhibit increased force output (i.e., acceleration) during the duration of the movement.

3. Subjects with a higher level of fitness will exhibit better accuracy in anticipating the timing of the completion of the movement.

Scope of the Problem

Other than athletes and the elderly, there is little research directed at young adults pertaining to the benefits of exercise and physical fitness level on motor coordination, especially the psychomotor component of coordination. It is well known that exercise improves physiological capabilities, and in some cases psychological factors such as mood state, but little is known about improvements in the psychomotor performance of young adults in light of general levels of physical fitness. In other words, is there a difference between fit and unfit young adults in regards to psychomotor performance?

Assumptions of the Study

For the purposes of this study, the following assumptions were made:

1. That the subjects were representative of males of high fitness and average fitness, and that the method of separating the groups based on aerobic fitness truly delineated those of high fitness from average fitness.
2. That the subjects would be honest in reporting their level of physical activity and sports participation.
3. The subjects gave full effort throughout all of the complex motor task testing.

Definition of Terms

1. Motor Control – an area of study dealing with the understanding of the neural, physical, and behavioral aspects of movement production.
2. Psychomotor – also referred to as perceptual motor; the component of movement production that involves large amounts of cognitive effort, information processing,

perceptual acuity, and decision making. These psychomotor components are often measured as multilimb coordination; precision or accuracy of movements; the ability to correctly and rapidly select what response should be made; reaction time speed (especially choice reaction time); speed and accuracy of hand or arm movements; timing or rate control of limb movements, manual dexterity that requires object manipulation with the hands or fingers while doing speeded movements, arm and hand steadiness, or speed of the hands or fingers, or ability to aim and objects in space (Fleishman, Quaintance, & Broedling, 1984).

3. Motor Coordination – patterning of body and limb movements relative to the objects and events in the environment. Thus, a finely coordinated movement efficiently utilizes the capabilities of the performer while taking into account the context in which the activity is performed and the constraints imposed by the environment.
4. Response Time – the interval from the presentation of the stimulus to the completion of the movement; the sum of the reaction time and the movement time.
5. Reaction Time – the interval from the presentation of an unexpected stimulus to the initiation of the response.
6. Movement Time – the interval from the initiation of a movement to its termination.
7. Choice Reaction Time – reaction time for a task in which each response to be made is associated with a different stimulus.
8. Force – a vector quantity that tends to produce an acceleration of a body in the direction of its application.

9. Accuracy – the exactness to which a task is accomplished. In the present study, the accuracy is the closeness to which the subject hits a target in terms of both spatial closeness and temporal closeness.
10. Anticipation Timing – timing of a motor action so that that action coincides with another event or is ready for an upcoming event. Anticipation timing requires the individual to anticipate, or predict, when environmental and individual motor acts will coincide. In the current study, individuals had to press a button during a rapid movement to coincide to when they felt they would hit a target.

Delimitations of the Study

The following delimitations were noted:

1. This study involved males between the ages of 18 and 24 enrolled at Ithaca College.
2. Cardiovascular fitness, as determined by VO2 max testing procedures, was used to classify fitness groups
3. Subjects were generally healthy with intact visual and neuromuscular systems.
4. Only right handed individuals are selected.
5. The movement was a choice reaction time task with a rapid arm movement response performed while standing.

Limitations of the Study

The following limitations were noted:

1. Results may only apply to 18-25 year old males.
2. Aspects of fitness other than cardiovascular fitness may affect motor coordination, however, results of this study only apply to cardiovascular fitness.
3. These results may not apply to individuals with visual problems, neuromuscular

problems or other health problems.

4. These results may not apply to left-handed or ambidextrous people.
5. These results may not apply to movements other than that employed in this study.

Chapter 2

REVIEW OF LITERATURE

Over the past century, the research conducted in the field of motor control is extensive. In particular, there has been considerable research specifically directed to developing a better understanding of the relationship between motor coordination and physical fitness. While this chapter certainly cannot touch on all of the research conducted to date, the literature referenced will provide a background for this research study and establish a basic understanding of the impact that physical fitness has on motor coordination. In order to better understand how motor coordination is affected by exercise, this chapter will discuss, (a) what is motor coordination, (b) the mechanics of motor coordination and psychomotor abilities, and (c) the impact of physical fitness on motor coordination.

What is Motor Coordination?

Humans create an innumerable variety of movements, ranging from the simple and mundane to the complex and thrilling. The quality of these movements, otherwise known as the level of motor coordination, has implications for one's general well-being. The process of producing a finely coordinated movement typically starts with an individual detecting a particular stimulus, mentally processing the information, selecting an appropriate action, activating the necessary muscle groups and coordinating the body to perform a fluid motion (Schmidt, 1982). The best means of understanding this process, and its importance, is by looking at a couple of examples.

Taken from America's national pastime, the first example involves a baseball player batting. With a wooden bat, the player steps into the batters box, holds the bat at the ready and prepares for the pitch. When the pitcher begins the windup to deliver the pitch, the batter watches the movement of the pitcher. As the pitcher releases the baseball, the batter focuses on the baseball, following it as it gets closer. At some point the batter makes a decision whether to swing the bat or not. If the batter decides to swing the bat, then the batter needs to coordinate the appropriate muscles to swing the bat at the appropriate time in order to make contact with the ball. What seems like a basic action actually involves significant interaction between the mind and the body in order to make contact with the baseball possible.

It is easy to see the implications of motor coordination in athletic skills such as batting. However, it is just as easy to see examples of motor coordination in everyday life. One activity that many adults engage in daily is driving. At some point in time during a daily drive, most drivers encounter a traffic signal. Imagine a driver accelerating toward an intersection with the traffic signal displaying a green light. As the driver draws near to the intersection, the traffic light turns yellow. The driver immediately sees this change and mentally processes the situation. The driver must then make a decision whether it is safe to proceed through the intersection or whether the car must be stopped. If the driver decides that the car must be stopped, then the muscles of the body need to be coordinated to remove the right foot from the gas pedal, place the right foot on the brake pedal and apply pressure. Sometimes, this type of movement is required with great quickness in order to avoid a collision. This is but one example of the role motor coordination plays in everyday life.

Whether talking about a baseball batter or a person driving a car, most motor activities begin with a stimulus. The stimulus is a thing or event that stimulates one of the senses and sparks an individual's mental processing of the significance of the event (Schmidt, 1975a). For instance, the baseball traveling toward the batter or the traffic light changing colors are both visual stimulus that the batter or driver observe. However, the stimulus is not limited to vision. The stimulus can be to sound, such as a gun being shot to start a race. The stimulus can be to touch, such as when someone taps another on the shoulder and the person turns to look. The stimulus can be through scent, such as when a person smells leaking gas and runs away. And the stimulus can even be through taste, such as when someone eats something they do not like and decides to spit it out. The significance of the stimulus event is that this is the point where the mental processing begins.

Once a stimulus is observed through one of the senses, the individual must then mentally process the information received (Annett, 1994). This aspect of motor control, that is, the psychomotor aspect, is affected by many factors, including experience and intelligence (Annett, 1994; Pew, 1970; Schmidt, 1975b). The fact that a ball is seen moving toward a person means nothing to the person unless that individual understands the situation. However, a batter, through experience, knows that he is playing a game that involves hitting a baseball that is thrown toward him. Therefore, the batter instantly begins mentally processing the situation once the baseball is thrown. Likewise, a driver, through experience, should know what the different traffic lights mean. When the individual confronted with a stimulus processes the meaning of the situation and understands that an action is required, the individual must then select the appropriate action.

Selection of the appropriate action in a given situation can be both simple and complex in nature. Take for instance a sprinter in the starting blocks at the Olympic Games. The sprinter waits for one stimulus, which is the gun shot, and will respond with one action, which is to begin running. The sprinter does not even have to decide whether or not to run, because there is only one action for the one stimulus. This is considered a simple task. However, there are situations where there may be more than one action that can be preformed for a given stimulus. This leads to a more complex situation, and thus is considered to be a complex task. Consider the driver again. This time the driver is behind another car, when the car in front suddenly comes to a halt. The driver is then confronted with a stimulus and has mentally processed the situation. However, the driver has more than one option. The driver could swerve to the right of the car, the driver could swerve to the left of the car or the driver could slam on the breaks. It is up to the driver to then take into account the entirety of the situation and then select the appropriate action to take.

While the concepts of a simple task and a complex task will be dealt with in more detail later, it is fairly simple to comprehend that an increase in the number of options available will lead to an increase in the time needed for choosing the appropriate action (Rosenbaum, Inhoff, & Gordon, 1984). There is consistent research that has proven that the more alternatives that an individual has, the greater amount of time the person needs to respond (Hick, 1952; Hyman, 1953). Researchers have used this observation to hypothesize that the additional delay due to the complexity of the decisions is a result of additional mental processing that the individual must conduct in order to make the appropriate choice (Donders, 1868).

After an individual selects the appropriate action in response to a given stimulus, the muscles of the body must be activated in order to begin movement. While the actual process of the mind controlling the body is still a mystery, it is established that the brain sends a series of well-planned electrical impulses down the spinal cord to motor nerves that activate the muscles. The nerves activate the muscles, causing the muscles to contract and the result is the movement of the body (Henatsch & Langer, 1985). The individual has the ability to activate muscles for small movements such as moving an arm or for full body movements such as running.

Once the muscles have been activated, the individual must coordinate the actions of the muscles in order to conduct a fluid motion that meets the requirements of the situation. Consider a person that is trying to jump across a small stream. The person can activate every single muscle in the body, but if the movement is not coordinated in such a way as to propel the individual across the water, then the only thing the person will accomplish is taking a bath. The coordination of the muscles requires control on the part of the individual and this type of control is gained through experience and memory.

Clearly, the ability to produce finely coordinated movements is an integral aspect of everyday life. While these examples help establish a cursory understanding of motor coordination, it is now time to examine in greater detail the intricacies of motor coordination and psychomotor abilities.

The Mechanics of Motor Coordination and Psychomotor Abilities

The examination of human motor coordination has led researchers to break down movements into distinct parts and create classification systems. Different parts of a movement, and different types of movement, have distinct meanings and characteristics that allow researchers to analyze how the parts interact with one another in the scheme of a movement. Although many aspects of movement can be evaluated, years of prior research have indicated that the key features of movement include some measure of timing, force, and accuracy. In particular, the psychomotor aspects of movement are most often reflected in movement speed and accuracy, precision and dexterity of arm and hand movements, the ability to control the rating and timing of movement sequences, and information processing speed as revealed by reaction time. In this section these variables are examined more closely.

As was discussed previously in the examples, when a person is confronted with a stimulus, the person must decide whether or not to perform a movement in response to the situation. In other words, the person has to decide whether to react to the situation. For the baseball batter, he has to decide whether to react by swinging the bat or not. The driver has to react by stepping on the break or not. The time it takes for a person to react to a stimulus and the time it takes for the person to complete the movement required in response to a stimulus are important features of movement that help identify the process of producing finely coordinated movements.

The time it takes to complete a movement is the response time (Schmidt, 1982). Response time is defined as the time from the onset of a stimulus to the completion of the movement. It encompasses the whole mental and physical processing of movement. The response time of a movement is broken down into two distinct parts. The first is the reaction time and the second is the movement time. Reaction time is the time from the onset of the stimulus until the beginning of the movement. Thus, reaction time signifies the time it takes from the stimulus presentment for the mind to process the information, make a decision and activate the muscles required for the movement. It is generally accepted that reaction time is considered to denote the time aspect of an individuals basic cognitive processes (Donchin & Coles, 1988). Movement time is the beginning of the movement (the end of the reaction time) until the completion of the movement (Schmidt, 1982). Therefore, movement time is indicative of the time it takes between the activation of the muscles and the completion of the movement.

The next important factor in understanding motor coordination is force (Irvy, 1986). Force is a factor of the speed or acceleration of the movement. The force of a movement, in essence, determines the speed at which the bodily component of the movement will be moving. For instance, if the batter decides to swing the bat as hard as he can, this will be more forceful than just an ordinary swing of the bat. With more force, the batter in essence, accelerates the bat to a greater degree through the course of the swing. One of the ways that force can be determined in motor coordination studies is to measure the acceleration of a movement. The more force exerted, the greater the acceleration.

The last major component of a motor task is accuracy. Accuracy is the degree to which the movement accomplishes the task set out to perform. This aspect of motor coordination studies provides a means of evaluating the degree to which a motor task is successful. The greater accuracy a person has when it comes to a motor task, the greater the person's motor coordination.

The interesting aspect of these motor variables comes to light when they are examined in relation to one another. Among the most important studies in motor coordination was one conducted by Fitts (1954). The study involved examining the relationship between speed and accuracy. The subjects in the study were required to move a stylus from one metal rectangular plate to another rectangular plate, tapping each plate before moving to the other plate. The movement between the plates took place for a total of 20 seconds. Throughout the course of the study, metal plates of different widths were used as targets. The purpose of the variable widths of the metal plates was that the smaller the width, the small the target and the greater the difficulty to tap the target. The data obtained from this study revealed an inverse relationship between speed and accuracy. As the difficulty of the task increased (through a smaller width of the targets), a decreased speed of movement was required in order to obtain a constant accuracy. This so called speed-accuracy trade-off showed that more time was needed to process a difficult task than an easier task in order to maintain a certain level of accuracy (Fitts, 1954).

The importance of the Fitts study lies in a basic understanding that it is better to be able to quickly and accurately perform a task. A person that can perform a task faster but with the same accuracy as another person will typically have an advantage. A driver who is capable of stepping on the break at a greater speed has a higher likelihood of avoiding a crash, than someone who is slower to react. Fitts' law is a robust measure that has been documented over and over again throughout many years (Burpee & Stroll, 1936; Engelhorn, 1997; Fitts, 1954; Hertzog, Vernon, & Rypma, 1993; Jensen, 1975; Sage & Hornak, 1978; Schmidt, 1982; Siegel, 1994; Southard, 1989; Woods, 1965; Woodworth, 1899; Wright & Meyer, 1983).

Just as there is an interesting interaction between speed and accuracy, there is also a similar interaction between force and accuracy. Multiple studies performed in 1978 through 1980 showed that as force increased, so did the variability in the accuracy of applying the force (Schmidt, Zelaznik, & Frank, 1978; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; Sherwood & Schmidt, 1980). In these studies, subjects were instructed to exert a set amount of force on a handle. The amount of force was set forth on an oscilloscope which the subject could see. The subject was to quickly exert enough force to fall within the target range set by the researchers. The data revealed that there was a direct relationship between the amount of force required and the variability of the force around the target number. As the force required increased, the variability of force increased. Another way to put this is that as the amount of force increased, the accuracy at which the subject could maintain that force decreased.

It was further discovered through these experiments, as the subject moved toward the maximum force that they could exert, the degree of variability of force began to decline. One study observed that at about a subject's 65% maximum force output, the degree of variability of force peaked and began to decline as a person reached their maximum force output (Sherwood & Schmidt, 1980). When an individual is instructed to exert maximum force output, it is like pushing up against a wall. The end result is relatively easy to accomplish. An individual's maximum force requires less in the way of strategy or technique, thus coordination is less variable. What is important to remember in examining studies of this type is that there is a distinct difference between the notion of variability and accuracy. Variability is a measurement of force output only, whereas accuracy goes beyond merely the force component by contemplating the goal of the motor task in its entirety. Due to the fact that most motor tasks require less than maximum force, these studies need to be kept in context. Because accuracy can be affected by the amount of force used, it is important, for purposes of motor coordination, that an individual take into account the amount of force that the person can control for the greatest accuracy (Kawabe-Himeno, 1991; Newell, Carlton, Carlton, & Halbert, 1980).

The impact of the interaction between force and accuracy gets some added support by research that was conducted that implied that while there appears to be an interaction between force and accuracy there was no real relationship between force and speed (Ito, 1997). The research conducted by Ito set forth a conclusion that the reaction time does not correlate to the amount of force a movement will have and, therefore, the degree of accuracy is not dictated by the reaction time but by the force. This conclusion sets forth an interesting dilemma when one considers this theory in light of the research by Fitts, as set forth earlier. Arguments can be made that both speed and force are inversely related to accuracy. That is, as both the speed and force of a movement increase, the accuracy of the movement becomes compromised. Yet, whether research can be conducted that can delineate to a greater extent the involvement of these two variables has yet to be determined.

These examples show that there is an interaction that exists between the various factors contributing to coordinated movements such that an individual has to be conscious of this interaction on some level in order to be successful in a given task. Through experience, an individual can learn at which speed and force they are the most proficient at performing a movement task. It takes a baseball batter substantial practice in order to understand the amount of speed and force required to hit a baseball. Yet, there is another factor of motor control that is important to such movements as batting.

In many motor activities, there is a requirement that combines timing and accuracy. Hitting a baseball is an easy example. The batter must not only focus on the baseball and coordinate a swing of the baseball bat, but he must also coordinate the swing of the bat with the movement of the baseball in order for the bat to meet the ball at the appropriate time. This is a classic example of coincidence timing. For a batter, it takes great control of one's motor capabilities to move the bat so that it coincides with the path of the oncoming baseball, resulting in contact between the bat and the ball. In order to accomplish this task, a batter has to take into account not only his movements, but also the velocity and movement of the baseball coming towards him. The studies conducted on a subjects' ability to coordinate timing and accuracy in a motor task revealed an interesting exception to the speed-accuracy trade off principle. Various studies actually revealed that as the speed of the task increased, such that the movement time was decreased, the accuracy actually increased (Schmidt et al., 1979).

These variables are at the heart of motor coordination. The ability to coordinate speed and force, along with any timing requirements, in order to make a fluid, accurate motion is a phenomenon that is worth examining more closely. Therefore, in order to help improve the ability of a person to perform a motor task, it is vital to conduct research aimed at developing an understanding of the various aspects of motor coordination. One way researchers looked to gain better understanding of high level motor coordination is to look at populations who have demonstrated a range of motor coordination, from the outstanding motor coordination of athletes to the failing coordination of elders. The next sections examine these populations more closely.

Motor Coordination and Athletes

A substantial amount of motor coordination research has been conducted on athletes. Athletes are typically defined as those individuals participating in some form of organized sports or competitive physical fitness activities. In order to obtain a heightened level of success, an athlete ought to possess an increased level of motor coordination during the athletic tasks that are performed as compared to a non-athlete.

There are numerous studies that have found athletes to have increased motor coordination over non-athletes (Smith, 1968; Youngen, 1959). Among the better abilities found in athletes have been a number of psychomotor abilities, such as reaction time (Keller, 1942). Reaction time is an important component of many athletic events, for instance, the ability to get off the starting block is of vital importance to a sprinter or a swimmer. Numerous studies have linked success in athletics to reaction time (Bhanot & Sidhu, 1980; Burley, 1944; Collet, 1999; Cureton, 1951; Elbel, 1940; Hubbard, 1956; Keller, 1942).

In 1942, a study was conducted with a subject group of 755 college and high school individuals. The groups represented both athletes and non-athletes, with athletes distinguished into specific sports. Reaction time testing revealed a positive relationship between success in athletics and an ability to quickly move the body. Interestingly, this study also found that athletes in team sports, such as baseball and basketball, possessed a quicker reaction time than athletes in individual sports (Keller, 1942).

More recently, in a 1992 study by Kerr and Boucher, research was aimed at determining whether motor coordination varied between athletes and non-athletes in a novel motor task. The task involved a tracking movement, whereby the subjects used a steering mechanism to line a pointer up with set points on the backdrop. The set points were lights that the subject was required to bring the pointer to. The next light would only be lit when the subject had appropriately lined up the pointer with the previous light. Therefore, these researchers were able to analyze not only reaction time data, but also accuracy. The results showed that during the course of the task, the athlete group was consistently faster and more accurate than the non-athlete group (Kerr & Boucher, 1992). These researchers concluded that athletes possessed a better understanding of their bodies' movements and thus are better able to control their movements.

One important issue that was brought forth by Kerr and Boucher (1992) was that they opined that previous studies on motor coordination may have been too narrow in their tasks to truly discern differences between the subject groups. The fact that these authors used a complex motor task, requiring the subjects to demand more both intellectually and physically, and that the results showed a significant difference between athletes and non-athletes, indicated to them that increasing the complexity of the task allowed for measurable differences between the groups.

This observation by Kerr and Boucher (1992) found merit in a study by Simonen, Videman, Battie, and Gibbons (1998). This study involved testing 38 pairs of identical twins, between the ages of 35 and 69. For each pair of twins, one person was a frequent exerciser and one was only an occasional exerciser. All of the subjects were tested on simple and choice reaction time tasks involving both the feet and the hands. While the study documented that there was a slightly better reaction time for the frequent exercisers as opposed to the occasional exercisers, the study revealed that it was easier to see the differences in the choice tasks than in the simple tasks.

Now, going back to the athlete population, a series of studies conducted by Beitel and Kuhlman in children revealed a correlation between motor control and participation in sports. The studies in children between the ages of four and nine revealed that after the children participated in sports for two years, there was an increased accuracy and a greater consistency of anticipation of coincidence (Beitel & Kuhlman, 1992; Kuhlman & Beitel, 1989, 1992). Thus, it is apparent that even participation at a young age in sports has an effect upon psychomotor abilities.

While it is well documented that athletes are able to respond to stimuli more quickly than non-athletes, the question still exists as to why. The most widely accepted theory revolves around training. Athletes spend large amounts of time practicing the movements required of them in their respective sport. Through practice the individual becomes more skilled in the movement and learns to control the movement to a greater degree. Examining the effect of training on motor control has been studied, specifically in regards to reaction time.

A study by Mokha, Kaur and Sidhu (1992) examined the effect of training on athletes. A group of hockey players were tested both before and after their training camp for foot and hand reaction times. The study concluded that at the completion of the training camp, the hockey players had improved their reaction time, thus affirming that it is possible through training to increase motor coordination, in particular reaction time. As mentioned previously by Kerr and Boucher (1992), through the use of one's body in physical activities, the person develops a better control of their movements.

Research in the field of karate revealed that while experts in the field are faster at choice reaction time tasks and exhibit better coordination in complex movements, they are no more accurate than novices in terms of specific movements (Mori, Ohtani, & Imanaka, 2002). This implies that there may not be significant differences between experts and novices in conducting portions of the complex tasks based upon accuracy, yet athletes are consistently better at motor coordination when required to complete the entire task (Harmenbert, Ceci, Barvestad, Hjerpe, & Nystrom, 1991; Yiou & Do, 2000, 2001). Thus, there must be some factor more than just training in an athlete which gives them an advantage over novices when full participation of the athletic task is accomplished.

Though an athlete's better motor coordination has been attributed to training, research has shown that athletes also possess a greater degree of motor coordination in novel tasks as compared to non-athletes. Increased motor coordination even in novel tasks by athletes can be explained by the theory that an athlete has a memory of the body movement experiences and therefore can adapt and learn a movement both faster and with a greater degree of proficiency than a non-athlete (Jackson, 1971; Kerr & Boucher, 1992; Steitz, 1963).

Another theory is that because athletes physically train and obtain high levels of physical fitness, their physiological systems are enhanced, which enables a greater degree of motor coordination compared to individuals with lower fitness levels (Youngen, 1959). The problem is whether the physiological and/or psychomotor benefit is due to the genetic disposition of the individual, is obtained through physical activity, or most likely, is a combination of both (Hascelik, Basgoze, Turker, Narman, & Ozker, 1989). This theory is less than developed for the athletic population due to the difficulty in isolating the source, but as is seen in the following section, studies have shown that as elderly individuals increase their level of fitness, they can experience an increase in motor coordination.

Motor Coordination and the Elderly Population

As individuals progress in age, physiological and psychological faculties steadily deteriorate. It has been found that after 25 or 30 years of age, there is a progressive decline in the physiological systems controlling motor function (Schmidt, 1982) and the ability to coordinate movement (Birren, 1964; Clarkson & Kroll, 1978; Hodgkins, 1962; Koga & Morant, 1923; Noble, 1978; Spirduso, 1975). The decline in motor coordination is not just limited to reaction time, but the elderly also experience a decline in coincidence-anticipation timing (Meeuwsen, Goode, & Goggin, 1997).

After the age of 60, human strength has been observed to decline noticeably (Hakkinen et al., 1996; Hakkinen, Pastinen, Karsikas, & Lannimo,1995; Larsson, 1978). Responsible for this deterioration of motor control is a breakdown of the cellular structures of the body, in particular a breakdown in the quality of central nervous system processing (Spirduso, 1975). As the nervous and muscular systems begin to weaken on the cellular level, the control over bodily movement is lessened (Booth, Weeden, & Tseng, 1994). Research shows that the number of functional motor units decreases in older individuals (Brown, 1972; Campbell, McComas, & Petito, 1973; Vandervoort, 2001). In addition, research shows that the number of muscle fibers also decreases as a person ages (Clarkson, Kroll, & Melchionda, 1981; Gollnick, Armstrong, Sanbert, Piehl, & Saltin, 1972; Lexell, 1995).

Studies have linked together the decrease in muscle fibers, or atrophy, with the aging process and a decrease in motor coordination. It is hypothesized that as a person ages, the skeletal muscle mass progressively reduces, leading to decreased contractile strength (Grimby & Saltin, 1983; Lexell, Henriksson-Larsen, Winblad, & Sjostrom, 1983; Lexell, Taylor, & Sjostrom, 1988; Rogers & Evans, 1993). This has been examined further, in that it appears that the loss in muscle mass is further affected by a decrease in the spinal motor nerves which lead to the loss of nerve impulse to the muscle fibers (Campbell et al., 1973; Doherty, 1993; Doherty, Vandervoort, & Brown, 1993). Studies reveal that with the decrease in muscle mass, an individual is significantly affected in terms of their strength output or the amount of force that the individual can exert (Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1998).

A more contemporary theory addressing the physiological implications of aging involves the concept of muscle remodeling. Simply, the concept entails a movement, or remodeling, of the muscle fibers from one type to another. The theory does not just entail the transition of fibers, but also incorporates metabolic changes, such as a shift in fuel towards glycolysis, the decreased capacity for fat oxidation and the accumulation of residual components in the atrophied muscles (Stein & Wade, 2005). Though the theories are still being developed on aging, the fact of the matter is that there is a natural progress that impacts all human beings, resulting in a breakdown of the physiological capabilities of the body.

Yet, a study conducted by Smith and Green (1962) revealed that when a person engages in frequent activities over the course of his or her life there is a less marked decrease in motor coordination compared to those activities that are conducted less frequently. Later, Botwinick and Thompson (1978) observed that some of their older active subjects had faster simple reaction times than their young non-active subjects, leading one to believe that activity level may help improve psychomotor coordination in the elderly. These developments formed the basis for the research accomplished in the 1970's through to the present day, leading to a significant hypothesis. The research conducted tends to show that elderly individuals who increase their level of fitness sustain motor coordination benefits (Clarkson, 1978; Kalapothariakos, Michalopoulos, Strimpakos, Diamantopoulos, & Savvas, 2006; Rotella & Bunker, 1978; Spirduso, 1975; Spirduso & Clifford, 1978; Xu, Li, & Hong, 2006).

In 1978, Clarkson conducted a study aimed at evaluating the difference between active verses non-active young and elderly males. The subjects were required to complete a motor task that required a foot movement in response to the stimulus lights. The study revealed that the older active individuals, that is, individuals who led a life style of active physical activity, possessed increased motor coordination in all categories, including reaction time and movement time. In addition, the active older subjects possess increased motor coordination in both simple and complex tasks. The conclusion by the author was that a lifestyle of physical activity enhanced the speed of central and peripheral neural processing, which was linked hypothetically to an increase in neural and muscular functioning through physical activity (Clarkson, 1978).

The effects of aging are noted to extend beyond simple movements to more complex coordination tasks. In a study that required both young and elderly participants to accomplish a high energy upper body coordination task between limbs, the elderly participants demonstrated a greater performance error for both the long movements and the shorter movements (Sparrow, Parker, Brendan, & Wengier, 2005). Also of interest in this study was the finding that the elderly groups displayed an increased heart rate during the motor task, which led the researchers to conclude that high energy coordination tasks, which increase heart rate, may decrease cognitive capabilities in elderly individuals since more oxygen is devoted to the performance of the task.

While the exact physiological pathway is still being examined, it is hypothesized that both strength training exercises and aerobic exercises may play a factor in preventing the degradation of both the muscular and neurological pathways (Doherty, 1993). Some speculate that enhanced physiological pathways, such as muscle hypertrophy and metabolic changes, contribute to better motor coordination in the elderly (Frischknecht, 1998). It has also been speculated that exercise contributes to an individual's aerobic capacity, which increases circulation and has a positive effect on the neurons that supply the muscle fibers (Dustman et al., 1984; McFarland, 1963; Spieth, 1965; Spirduso, 1980, 1982). This is supported by substantial research corroborating a correlation between oxygen supply and cognitive functioning (Fowler, Taylor, & Porlier, 1987; Jacobs, Winter, Alvis, & Small, 1969). While strength training and aerobic exercise have been shown to increase physiological outcomes and psychomotor performance in the elderly (Christensen, Payne, Wughalter, Yan, Hanenhan, & Jones, 2003), research exists that indicates that the benefits derived from exercise comes from actual activity levels. That is, if a person stops physical activity at an older age, the motor coordination benefits will be lost (Gauchard, Tessier, Jeandel, & Perrin, 2003). However, the relative contribution of physiological versus psychomotor benefits on motor coordination remains a topic of debate (Ives & Shelley, 2003).

More recently, the use of functional magnetic resonance imaging (fMRI) has fostered further support that cognitive functioning is related to blood flow. Blood oxygen level-dependant fMRI is conducted by examining the changes in the blood flow and hemoglobin concentration in the microvasculature (Oguz et al., 2003). When a person conducts a movement, certain areas of the brain are activated, and this can be seen on an fMRI scan. Studies reveal that as a person ages, the person generally exhibits decreases in vascular supply and neurons and experiences changes in the histological structure of the microvasculature, all of which contribute to the decreased activation in the brain (Oguz et al., 2003). This impediment due to aging is thought to be the process behind the increased lag in reaction time in elderly individuals as compared to younger individuals (D'Esposito, Zarahn, Aguirre, & Rypma, 1999; Hesselman, Zaro, & Wedekind, 2001).

Another theory that is being entertained pertaining to an explanation for motor declines in the elderly emphasizes free testosterone and total testosterone levels. It has been observed that in the elderly there is both a decrease in free testosterone and total testosterone levels (Uyanik, Ari, Gumus, Yigitoglu, & Arslan, 1997). Further, it was noted that in right handed and left handed men, serum testosterone levels were associated with nonverbal intelligence and nonverbal spatial reasoning (Tan, 1990a,b; Tan, Akgun, & Telatar, 1993; Tan & Tan, 1998). Speculation was made that this increase in testosterone in men and the relation to nonverbal intelligence stems from an evolutionary process. A recent study by Ari, Kutlu, Uyanik, Taneli, and Buyuyazi (2004) examined the motor coordination between physically active and sedentary elderly males in light of serum testosterone levels. The active group had noticeably greater oxygen consumption (VO2 max) and faster reaction times. A positive correlation was noted to exist between level of fitness and serum testosterone levels. It was concluded that long term exercise increases serum testosterone levels in the elderly which may be advantageous to brain function.

In addition to serum testosterone, other factors are also being actively investigated that may correlate to the aging process. Studies have shown that the administration of growth hormone and insulin-like growth factor-1 have resulted in increased muscle mass, a decrease in adiposity, increases in immune function and improvements in learning and memory (Bartke, 2005; Dik et al., 2003; Khan, Sane, Wannenburg, & Sonntag, 2001). Studies have also shown, that much like with serum testosterone, estradiol depletion can impact the brain, resulting in memory and learning problems (Foster, Sharrow, Kumar, & Masse, 2003; Wise et al., 2001). Finally, low levels of dehydro-3-epiandrosterone, or DHEA, are associated with aging, including cardiovascular disease in men (Johnson, Bebb, & Sirrs, 2001). The verdict is still out as to the impact of exercise and physical activity in the elderly on these factors.

Of great importance to this field is that current technology presents ways of analyzing motor coordination that were not available in the past. In particular this is seen in the field of neuroscience. It has long been suspected, as set forth previously in this section, that one of the physiological pathways thought to play a key role in the decline of motor coordination in the aged is neurological. That is, that the neurological pathways, much like the musculoskeletal pathways, deteriorate with age, thus making the coordination of movement more difficult. It was one thing to speculate about this, but it was another to attempt to prove such. Today, in the age of magnetic resonance imaging, positron emission testing and transcranial magnetic stimulation, examination of the neurological pathways of the brain is becoming commonplace and finding a significant place within the realm of research on understanding the neurophysiological impact of aging and exercise on the brain. Transcranial magnetic stimulation has made it possible to show that through the use of specific muscle groups, the areas in the brain responsible for motor activity, such as the motor cortex, show enlargement of activity in the respective areas (Asanuma & Pavlides, 1997; Charlton, Ridding, Thompson, & Miles, 2003; Classen, Liepert, Wise, Hallett, & Cohen, 1998; Gerloff, Corwell, Chen, Hallett, & Cohen, 1998; Liepert, Tegenthoff, & Malin, 1995; Pascual-Leone et al., 1995). This process was further documented by the difference noted in musicians, who are required to acquire and perform specific motor skills. Keyboard players and string players had an increased length of their precentral gyrus, which is an indirect measurement of the motor cortex. The study concluded that the motor cortex can undergo structural adaptations from functional use (Amunts et al., 1997).

It is interesting that recent studies on animals have shown that implementing light levels of regular physical activity significantly improve learning and actually increase the neuron density of areas of the brain, specifically the hippocampus and the gyrus dentatus, that affect cognitive processing (Uysal et al., 2005). The researchers hypothesized that this same type of occurrence may be evident in the human populations. This speculation is supported by a meta-analysis conducted by Calcombe and Kramer (2003) setting forth evidence that fitness training in the elderly has noticeable cognitive benefits, in particular for executive control processes (Calcombe & Kramer, 2003). From this research, it appears that the ability to enhance one's cognitive state and neural pathways is available even late in life.

The best measure of physical fitness for purposes of evaluating motor coordination in subject populations like the elderly is through VO2 max testing (Howley, Bassett, & Welch, 1995). A study by Era, Jokela, and Heikkinen (1986) examined subject groups based on direct maximum oxygen consumption (VO2 max) testing. Three groups of subjects were tested, ranging in ages from 31-35, 51-55, and 71-75, for reaction and movement time tasks. The results of the study showed that the aerobic capacity of the oldest age group was positively correlated with increases in motor control. Of note, is that this study used direct VO2 max testing, as opposed to estimated or submaximal VO2 tests, to group the subjects. Direct testing of VO2 max is through the use of specialized testing equipment that directly measures the output of CO2 and O2 from a person during exercise and equates this to the person's aerobic capacity. Submaximal or estimated VO2 max testing uses equations to estimate a persons VO2 max without actually obtaining persons maximum aerobic capacity during the testing. Obviously, the direct testing of VO2 max is more accurate, however, this testing requires the availability of the testing equipment and the testing requires a considerable commitment from the testing population to participate in what is considered a vigorous testing procedure.

If the elderly population can obtain motor coordination benefits through exercise, and not necessarily through specific skill related practice as with athletes, then what about the benefits of increasing the level of fitness in a younger individual? Does a younger individual, who is not an athlete, obtain similar motor coordination benefits simply as a result of increasing one's level of fitness?

Motor Coordination and the Young Adult Population

The research available on the young adult population, ages 18 to 25, pertaining to the effect of exercise on psychomotor skill performance is limited. Abundant research shows that young adult athletes can improve in psychomotor skills and overall motor performance as a result of physiological training and specific practice (Mokhu et al., 1992), but less is known about non-athletes who do not engage in rigorous training or practice. For these non-athletes there may be some improvement in motor coordination that can be attributed to experience and continuing physiological maturation (Schmidt, 1982), but the role of general fitness training in maintaining or improving psychomotor performance is relatively unknown. A limited body of research does, though, tend to support the idea that a young adults' general fitness level may contribute to their psychomotor performance.

Studies on young adults between the ages of 18 and 25 years old, which deal with exercise and psychomotor coordination, often are conducted during the course of an exercise session. For instance, a study by Arcelin, Delignieres and Brisswalter (1998) involved the administration of a motor task while the subject was cycling on an ergometer. The purpose was to examine the effects of exercise on cognitive processes. The results indicated that the subjects performed the motor task better, such as faster reaction times, than when the task was conducted at rest. Of particular interest in this study is that the reason hypothesized for the decreased reaction times was due to an increased awareness or arousal during exercise that is not present at rest. A similar study by Yagi, Coburn, Estes, and Arruda (1999) examined a subject population of college students with a mean age of 20. The subjects were tested with visual and auditory stimulus in three different conditions, at a resting baseline, during aerobic exercise and during the recovery period. This study found that the reaction times to both auditory and visual stimuli were decreased during exercise, however, the amplitude decreased during exercise and the error rates increased during exercise. The researchers speculated that the reaction time decrease was due to increased arousal, but that the decrease in amplitude was largely due to a decrease in the ability to reallocate attention during exercise.

The studies by Arcelin (1998) and Yagi (1999) were aimed at examining the immediate effect of exercise on motor coordination, specifically, how cognitive processing and attention are affected by arousal and fatigue. These studies are designed to research the impact of exercises immediate effect on motor control as opposed to the long term effects of exercise on an individual (Isaacs & Pohlman, 1991). The acute impact of exercise on cognitive processing is generally attributed to an increased level of arousal during exercise, resulting in an increased ability to focus on the task at hand (Cote, Salmela, & Papathanasopoulu, 1992). While the studies on arousal are limited in their ability to pinpoint the optimal level of exercise required to maximize motor coordination benefits, they do, however, suggest that young adults' psychomotor performance can be influenced by aerobic exercise (Davranche, Burle, Audiffren, & Hasbroucq, 2006; Davranche & Audiffren, 2004; Davranche, Audiffren, & Denjean, 2006; Hillman, Snook, & Jerome, 2003).

A cross-sectional study of aerobic fitness and psychomotor performance was conducted by Forth and Salmoni (1988), who looked at reaction times among three groups of young individuals, grouped by ages 10-11, 17-18 and 23-24. All the subjects were required to complete a physical activity questionnaire which documented the subjects' physical activities during the prior two weeks. The researchers converted the activities into energy expenditure units (METS), which was used as an activity level variable for the study. The subjects then completed a graded treadmill run for maximum aerobic capacity. At the next session, the subjects completed simple and complex reaction time testing, which included four blocks of 20 trials for each reaction time condition. Between blocks of trials, the subjects were given a two minute break. Interestingly, the oldest group was the only group that drew a correlation between reaction times and aerobic capacity. The rationale behind this finding was that the younger groups were still maturing and, thus, there was no statistically noticeable different between the subjects. However, in the oldest group, there may have been a cumulative effect of fitness over the years, making aerobic capacity a bigger factor in their motor coordination (Forth & Salmoni, 1988).

The long term effects of exercise on young adults' psychomotor performance were examined in a study conducted by Powell (1983), who examined subjects with a mean age of VO2 max testing before and after a seven week aerobic training program. The training program involved one hour of continuous physical activity for five mornings per week. Both pre and post treatment, the subjects were administered five blocks of five simple reaction time trials and five blocks of ten choice reaction time trials. After the conditioning program the subjects demonstrated an increased VO2 max and increased strength. While not statistically significant, the data seemed to suggest that the choice reaction times became faster after the conditioning. The author concluded that the seven week program was not long enough to create marked changes.

These studies are inconclusive in demonstrating an association between a young adult's maximum aerobic fitness level and his or her psychomotor performance, but that may be due to methodological shortcomings. It is well established that the best objective indicator of a person's physical fitness is the maximum aerobic capacity (Astrand, 1956; Linde, 1963; Taylor, Wang, Rowell, & Blomquist, 1963). Further, it is generally accepted that VO2 max data is the best single indicator of physical fitness (Howley et al., 1995). Studies reveal that only directly assessed VO2 max correlates significantly with motor coordination, as opposed to indirect measurements of VO2 max (Era et al., 1986). Since the differences in psychomotor skills between fit and less fit people are more observable as people get older, finding smaller differences in younger populations requires more precise methodologies (Kerr & Boucher, 1992).

<u>Summary</u>

Years of research has shown that young adult athletes can improve their psychomotor performance through some combination of specific skill-related practice and rigorous fitness training. Research on elderly persons indicates that psychomotor performance can be maintained, and even improved, by fitness training alone. In particular, engaging in aerobic exercise and maintaining aerobic fitness has been shown to maintain psychomotor abilities in elders. Maintaining these psychomotor abilities is likely a result of the physiological changes that take place in the central nervous system resultant from years of physical exercise.

Limited research is available on the young adult population, ages 18 to 25, regarding physical fitness and psychomotor performance. Evidence is available, though, that does suggest that psychomotor performance may be enhanced in fit young adults, but precise methodology is necessary to tease out these enhancements. Since maximum aerobic capacity testing is considered the best indicator of an individual's physical fitness, a study is needed to evaluate the psychomotor capabilities of young adults grouped according to their maximum aerobic capacity. The purpose of the current study is thus to evaluate the psychomotor performance between young adult males who are fit verses those who are less fit based upon aerobic fitness level (maximum oxygen consumption). Specifically, the performance on a complex psychomotor task, including reaction time, anticipation timing, limb movement speed, and target accuracy, is compared between young adult male non-athletes who are fit versus those that are less fit. The results of this study provide relevant information pertaining to the psychomotor benefits of exercise.

Chapter 3

METHODS

The purpose of this study was to examine if physical fitness levels in young adult males are associated with differing psychomotor performance. The methods were designed to evaluate performance on a complex psychomotor task and to precisely measure aerobic fitness level based on maximal oxygen consumption (VO2 max). Described in this chapter are the subject population, testing apparatus, procedures and variables of interest.

Participants

The subjects for this study were selected from the volunteers who responded to the fliers and announcements that were posted on the Ithaca College campus. Those that volunteered signed an informed consent form (Appendix A), prepared according to Ithaca College guidelines and approved by the Human Subjects Review Board. Participants completed a Physical Activity Form (Appendix B) to determine their level of physical activity and sport involvement, and a Physical Activity Readiness Questionnaire (PAR-Q: Canadian Society for Exercise Physiology, Inc., 1994) (Appendix C) to screen for exercise risk factors. Participants that engaged in any collegiate level organized sport program were deemed athletes and removed from the study.

Twenty-one volunteers responded to the study. One individual was excluded after failing the color blindness test. Two individuals were excluded for not being able to complete VO2 max testing. From the time of selection to the end of testing, four other individuals failed to complete the study. The resulting sample population was fourteen subjects divided into two groups (Fit: $\underline{n} = 7$; Less Fit: $\underline{n} = 7$) based upon VO2 max gathered from the maximal graded exercise test. The Fit group had a mean VO2 max of 56.6 ml/kg/min and the Less Fit group had a mean VO2 max of 43.2ml/kg/min.

Testing Procedures

Following completion of the informed consent form, the Physical Activity Questionnaire, and the PAR-Q form, the subjects were tested for a number of anthropometric and physical fitness variables during week one. Participants were briefed on the testing apparatus and what was required of them. They were tested for vision (Snelling Eye Chart) and color-blindness (Dvorine Pseudoisochromatic Plates). Weight, height, right arm length, seven point skinfolds and girth measurement data was collected pursuant to the American College of Sports Medicine protocols (ACSM's Guidelines for Exercise Testing and Prescription, 2000). Anaerobic strength data was collected using a right hand grip strength test and a 1-repetition maximum bench press test (ACSM's Guidelines for Exercise Testing and Prescription, 2000). Cardiovascular fitness level was obtained using direct VO2 max testing. The anthropometric and physical fitness tests are described in more detail below.

The second week of testing began with two consecutive days of testing each subject on a complex psychomotor task. The task, described in more detail below, was a four-choice reaction time task requiring the subject to stand while making rapid arm movement responses to a red or green light stimulus. Each test day consisted first of 12 practice trials followed by two sets of trials. Each set consisted of 40 trials. Between each set of trials was a brief rest of one minute. The order of presentation of the four stimulus-response choices were randomly selected from a group of pre-ordered randomly selected sheets. These procedures were repeated on the second day. The subjects were instructed to complete each task as quickly and as accurately as possible.

Psychomotor Testing Apparatus

The testing apparatus was designed for the purposes of this study to provide the appropriate stimulus and movement parameters needed for a discrete, open movement scenario. The apparatus and task were designed to enable four stimulus-response choices in a rapid arm movement response time task. A unique feature of this apparatus was that the subject was required to stand while performing this task. By having the subject stand the task becomes more of a whole body task, which enables the use of numerous movement strategies not available to one who is seated. These movement strategies might be different between persons who are fit versus those that a less fit (see Appendix D for a schematic of the apparatus).

The testing platform was a semi-circular plywood base, parallel with the floor, with white tack paper lining the top. The entire testing platform was capable of being raised and lowered depending on the height of the subject. The front of the platform was the curved portion, which faced the subject. At the back edge of the platform, located in the middle, was a rotating axle that extended vertically through the platform. Attached to the axle, underneath the testing platform, was a lever extending from the axle out to where the subject was standing. This lever extended out beyond the platform and had a vertical handle that the subject grasped. Also attached to the axle, but on top of the platform, was a dowel rod with a fine metal pointer. The dowel rod was exactly in line with the lever beneath the platform, and the rod pointer was aimed directly at the lever handle. When the lever beneath the platform rotated along the axle axis, the dowel rod moved in line with it.

On top of the platform, along the curve, were five points measured from the axis of rotation of the rod pointer. All five points were 12 inches from the axis of rotation. The center mark – also serving as the start position for the rod pointer – was at 0 degrees. Target marks were then made at 15 and 30 degrees to the left of the start position (requiring a clockwise movement of the lever and pointer), and 15 and 30 degrees to the right of the start position. The 15 and 30 degree target marks to the right required a counterclockwise movement of the lever and pointer, and were labeled as the -15 and -30 degree targets. At each of the four target marks were small rubber posts, colored yellow at the 15 degree marks and orange at the 30 degree marks. The pointer was elevated about .5″ above the testing platform. The tip of the pointer was exactly 12″ from the point of rotation. As the lever arm was swung by the subject, the pointer would move and just swipe the rubber pegs, providing both visual and tactile feedback to the subjects on their positioning. The pegs, though, provided negligible resistance to movement, especially as the pointer moved through the 15 degree pegs to get to the 30 degree pegs.

The vertical handle extending up from the lever allowed the subject to grasp the handle with the right hand and freely move the lever to the left (clockwise) or to the right (counterclockwise). On the top of the handle was located a button switch that the subject could depress with the thumb of the right hand. The switch sent a timing signal to the data collection apparatus.

At the front of the platform, near the start position, were three light-emitting diodes (LED, KingBright, Industry, CA) arranged front to back. The LED closest to the subject served as a yellow warning light. The next two LEDs displayed either a green or a red stimulus light. The lights were connected to the controller box, which allowed the tester to turn on the lights as needed.

The apparatus was instrumented to collect kinematic and reaction time data. Affixed to the axis of rotation of the lever was a precision linear potentiometer (Mouser Electronics, Mansfield, TX) to gather displacement data. On the lever arm, twelve inches from the axis of rotation, was attached an accelerometer (Model G50, Biopac Instruments, Goleta, CA). Movements to the left and right measured both positive and negative acceleration. Both displacement data and acceleration data was routed through a Biopac data collection system (Biopac Instruments, Goleta, CA) to a pentium-based personal computer. All raw data were analyzed off-line using Acknowledge v. 3.7 software (Biopac Instruments, Goleta, CA).

When a stimulus light was activated by the researcher, the computer was triggered to collect data. Thus, the onset of data collection signified the onset of the stimulus. When the subject depressed the button on the handle, the computer stopped data collection. The Acknowledge software permitted the measurement of reaction time, movement time, movement accuracy, peak positive acceleration, and peak negative acceleration.

Psychomotor Task

The task consisted of four stimuli with four different arm movement responses. A warning light was given to allow the subject to know that the stimulus would be presented shortly. The time between the warning and the stimulus presentation is varied with up to a four second delay. The stimuli were one green light, one red light, two green lights, and two red lights. Given the appropriate stimulus, the subject had four movements to choose from. Green lights signified arm movements to the left (mostly horizontal shoulder adduction with inward rotation), red lights signified arm movements to the right (mostly horizontal shoulder abduction with external rotation). One light indicated a 15 degree (short) movement, and two lights indicated a 30 degree (long) movement. Thus, one green light provided the stimulus for a 15 degree movement to the left, and two green lights was a 30 degree movement to the left. One red light was a 15 degree movement to the right, and two red lights was a 30 degree movement to the right.

The subject stood with feet shoulder width apart, facing the apparatus. The subject's right hand is placed upon the apparatus handle. The subject is able to see the lights and the pointer in the same field of view. The height of the platform was adjusted so that the subject's elbow was flexed about 90 degrees. The subject's thumb was placed on the button located at the top of the handle.

The subject received a yellow warning light to let him know that the stimulus was coming. Within four seconds came the stimulus. The subject was instructed to react to the stimulus as fast as possible – making the correct choice of a long or short and left or right response – move the lever as fast as possible to the correct target peg, and then stop the lever directly on the target peg. The subject was instructed to press the button on the handle to coincide with hitting the target. Thus, the subject had to anticipate when to press the button so as to match the button press with the exact time of hitting the target.

After familiarization with the apparatus, the subject was given three practice trials at each of the four different stimulus-response conditions, for a total of 12 practice trials. Following practice, the subject was given 10 trials at each of the four different stimulus-response conditions for a total of 40 trials. The subject was given a brief rest of one minute and repeated the block of 40 trials. The order of presentation of the different stimulus-response conditions was randomized within each block of 40 trials. On the second day of testing the 12 practice trials and two blocks of 40 trials were repeated.

Anthropometric and Physical Fitness Testing

First, measurements of height and weight were recorded and a seven-site skinfold test to determine body composition was done according to procedures set forth by the American College of Sports Medicine (ACSM's Guidelines for Exercise Testing and Prescription, 2000). The generalized skinfold equation used to calculate body density was adapted from Jackson and Pollock (1985). Likewise, ACSM guidelines (ACSM's Guidelines for Exercise Testing and Prescription, 2000) were used in measuring waist girth, hip girth, and one repetition maximum bench press testing. One repetition maximum bench press data was normalized by dividing the amount of weight lifted by the persons' body weight and comparing the percentage to known data ranges (Institute for Aerobics Research, 1994).

Maximum cardiovascular fitness was obtained by measurements taken through a VO2 collection system (Parvo Medics, Salt Lake City, UT). The subject, after a brief warm up period of walking for two minutes at zero degree elevation, began running at a subjectively brisk pace at 0 degrees elevation for one minute, with a two degree incline added each minute thereafter. The subjects ran until exhaustion. The VO2 collection system was calibrated by using known gases prior to each test and the resulting VO2 was recorded in ml/kg/min. The VO2 max data were the only data used to group subject populations of fit versus less fit for purposes of this study. The reason for this decision was the scope and purpose of this study and the known correlation between VO2 max and cardiovascular fitness.

Criterion Measures and Data Analysis

Measurements were conducted for the variables reaction time, movement time, acceleration, negative acceleration and accuracy of anticipation timing (see Appendix E for a detailed sample data schematic). Reaction time was measured as the time from the onset of the stimulus to the time that the lever displacement began. Movement time was measured from the beginning of the lever displacement to the time at which the thumb trigger was depressed. The displacement of the lever was measured by the goniometer located in the axle and routed to the computer (see Appendix D, Side View of Apparatus). Acceleration and negative acceleration were recorded in the computer via the accelerometer placed on the lever arm (see Appendix D, Side View of Apparatus). Accuracy was determined by measuring the angle at which the thumb trigger was activated and the known 15 and 30 degree marks. The difference between the actual mark and the target mark determined the anticipation timing accuracy of the task. When recording the accuracy data, if the subject went beyond the target mark, a positive degree differential was noted. If the subject fell short of the target mark, a negative degree differential was noted. Thus, for accuracy, the resulting average is a mean of total deviation from the target taking into account both positive and negative scores.

Once all of the subject data were collected, the computer data were analyzed. From each trial, a numerical value was obtained for reaction time, movement time, acceleration, negative acceleration and accuracy. Raw data were placed into a spread sheet document separating out each subject's data by Day, Set, and Stimulus Type. Thus, each subject participated in two days of testing, with two sets on each day for a total of four sets. Each set consisted of 10 trials each of four different stimulus response movements of Left-Short (15 degree adduction, Left-Long (30 degree adduction), Right-Short (15 degree abduction), and Right-Long (30 degree abduction).

After all the data were transcribed into the spreadsheet they were rechecked twice for errors in transcription. Data for each subject were then analyzed individually by Day, Set and Group. Thus, each subject had 16 blocks of 10 trials with five variables measured. A simple average and standard deviation measurement was taken for each block of 10 trials and each trial was examined in light of the standard deviation. Any data point, from any variable, that fell outside of two standard deviations of the average was marked as suspicious. All suspicious data were then evaluated in light of the remaining variables for the set. The researcher's discretion was used to determine whether the trial was flawed. If any variable was deemed to be flawed, then the entire trial was discarded. About one percent of the data were discarded.

All remaining trials were averaged for each day. Thus, trial to trial and block to block differences were not analyzed, for these differences were not germane to the research questions. These data were then analyzed using a 2 x 2 x 4 repeated measures analysis of variance (ANOVA). The factors were Groups (Fit, Less Fit), Days (Day 1, Day 2), and Stimulus-Response Conditions (Left-Short, Left-Long, Right-Short, Right-Long) with repeated measures on the Day and Condition factors. In the case of significant interactions, simple main effects with pairwise comparisons were calculated to locate the source of the interaction. All analyses were done using SPSS v. 13 statistical software. A significance level of alpha = .05 was used.

Summary

This study was designed to examine two groups of young adults, grouped according to their maximum aerobic capacity, for differences in motor control. The subjects' maximum aerobic capacity was directly tested and the subjects were grouped based upon this data. The testing apparatus created a novel complex motor task capable of collecting data on reaction time, movement time, acceleration, negative acceleration and accuracy. The complex motor task consisted of four different stimuli that required four separate responses. The subject was required to complete a response to each stimulus presentation as quickly and as accurately as possible. Feedback was given after each movement pertaining to the accuracy of the movement. The subjects performed two days of testing, each day consisting of practice trials and two separate sets of 40 stimuli presentations. The data collected was analyzed by repeated measures ANOVA for differences between the Groups, Days, and Conditions.

Chapter 4

RESULTS

This chapter is organized based upon the six motor control variables measured in this study. For the variables of reaction time, movement time, response time, acceleration, negative acceleration, and accuracy, statistical analysis was conducted with the data set forth in this chapter. For each variable, the analysis began with a compilation of the means and standard deviations by Groups, Days and Conditions. An analysis of variance was then conducted and, if there was any significant interactions, further analysis was conducted by examining simple main effects with pairwise comparisons in attempts to locate the source of the interaction. The results of these analyses are set forth variable by variable in this chapter.

Participant Characteristics

Fourteen subjects completed this research from beginning to end. Prior to the administration of the choice reaction time testing, fitness and anthropometric testing was conducted on each subject. The subjects were tested for maximum oxygen consumption, resting blood pressure, one repetition maximum bench press, seven-site skinfold measurements, girth measurements and hand grip dynamometry. However, only the maximum oxygen consumption (VO2 max) data were used to group the subjects (Table 1).

Independent t-tests were conducted to compare the anthropometric and fitness variables of the groups. The Fit Group had a significantly ($p < .001$) greater maximal oxygen consumption, a significantly ($p = .006$) stronger relative muscle strength, and a significantly ($p = .023$) lower resting systolic blood pressure. The groups were similar in

Table 1

Anthropometric and Fitness Data for the Fit and Less Fit Subject Groups

	Fit (n=7)		Less Fit (n=7)	
	Mean	SD	Mean	SD
Age (years)	19.9	0.8	20.6	2.1
Height (cm)	177.3	7.3	180.6	4.0
Weight (kg)	77.1	6.8	81.1	12.5
Systolic Blood Pressure (mmHg)	126.9*	10.5	138.4	5.3
Diastolic Blood Pressure (mmHg)	80.7	4.7	79.9	10.7
VO2 Max (ml/kg/min)	56.6**	4.57	43.2	4.45
1 Repetition Max Bench Press Ratio (maximum weight lifted/body weight)	1.31**	0.28	0.91	0.11
% Body Fat	11.5	5.7	13.6	7.7
Body Mass Index	24.6	2.17	24.8	3.54
Waist to Hip Ratio	0.84	0.04	0.81	0.03
Handgrip (lbs)	59.6	7.5	51.4	11.9

* Fit group significantly differs from the Less Fit group, $p < .05$
** Fit group significantly differs from the Less Fit group, $p < .01$

age, height, weight, body composition and body mass index. These results indicate a successful grouping of Fit and Less Fit groups.

Reaction Time

Means and standard deviations for reaction time are presented in Tables 2 and 3, and ANOVA results are presented in Table 4. The Fit group (M = 185 ms, SD = 74) had a 23% smaller mean reaction time than the Less Fit group (M = 239 ms, SD = 91), but this result did not reach a statistical significance [$F(1,12) = 3.29, p = .095$]. The ANOVA results revealed statistically significant Day (p = .0008) and Condition (p = .0000) main effects. These effects, however, were confounded by a significant Day x Condition interaction [$F(3,36) = 7.45, p = .0005$].

In order to identify the source of this Day x Condition interaction, simple main effects with pairwise comparisons were done to compare the Day 1 to Day 2 differences for each condition. Table 5 reports the results of the pairwise comparisons for each day and Figure 1 illustrates this interaction. As reported, all of the conditions were faster on Day 2 except for the Left-Long condition.

In summary, the Fit group tended to be faster than the Less Fit group, albeit this result was not significant. In all cases except for the long movements to the left, reaction time was faster on the second day.

Movement Time

Means and standard deviations for movement time are presented in Tables 6 and 7, and ANOVA results are presented in Table 8. The Fit group was 19% faster overall, but this effect was not statistically significant. The Condition main effect was statistically

Table 2

Means (M) and Standard Deviations (SD) for Reaction Time Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M (s)	.181	.228	.238	.151	.200	.121	.234	.212	.112	.170
SD	.039	.052	.046	.052	.058	.053	.092	.064	.054	.085
Less Fit (n=7)										
M (s)	.240	.311	.289	.197	.259	.169	.287	.255	.165	.219
SD	.057	.092	.068	.042	.079	.062	.102	.088	.080	.098
Both Groups (n=14)										
M (s)	.211	.269	.264	.174	.229	.145	.261	.234	.139	.195
SD	.056	.084	.062	.052	.075	.062	.099	.079	.072	.095

Table 3

Means (M) and Standard Deviations (SD) for Reaction Time Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (s)	.152	.231	.225	.132	.185
SD	.055	.073	.056	.056	.074
Less Fit Group (n=7)					
M (s)	.204	.299	.272	.181	.239
SD	.069	.096	.079	.065	.091
Both Groups (n=14)					
M (s)	.178	.265	.249	.156	.212
SD	.067	.091	.072	.065	.087

Table 4

Group x Day x Condition Repeated Measures Analysis of Variance for Reaction Time

Source	*df*	SS	MS	*F*	*p*
Group	1	.083	.083	3.29	.0950
Subject					
GxS (error)	12	.303	.025		
Day	1	.034	.034	19.86	.0008*
Group x Day	1	.001	.001	0.44	.5205
GxSxD (error)	12	.021	.002		
Condition	3	.236	.079	56.84	.0000*
Group x Condition	3	.002	.001	0.46	.7090
GxSxC (error)	36	.050	.001		
Day x Condition	3	.012	.004	7.45	.0005*
Group x Day x Condition	3	.001	.000	0.76	.5230
GxSxDxC (error)	36	.019	.001		
Total	111	.760			
Grand Mean	1	5.030			

*Statistically significant at $\alpha = .05$

Table 5

Means (M) and Standard Deviations (SD) for Reaction Time Nested by Days and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Day 1					
M (s)	.211	.269	.264	.174	.229
SD	.056	.084	.062	.052	.075
Day 2					
M (s)	.145**	.261	.234**	.139**	.195
SD	.062	.099	.079	.072	.095
Both Days					
M (s)	.178	.265	.249	.156	.212
SD	.067	.091	.072	.065	.087

** Day 2 significantly different from Day 1, $p < .01$

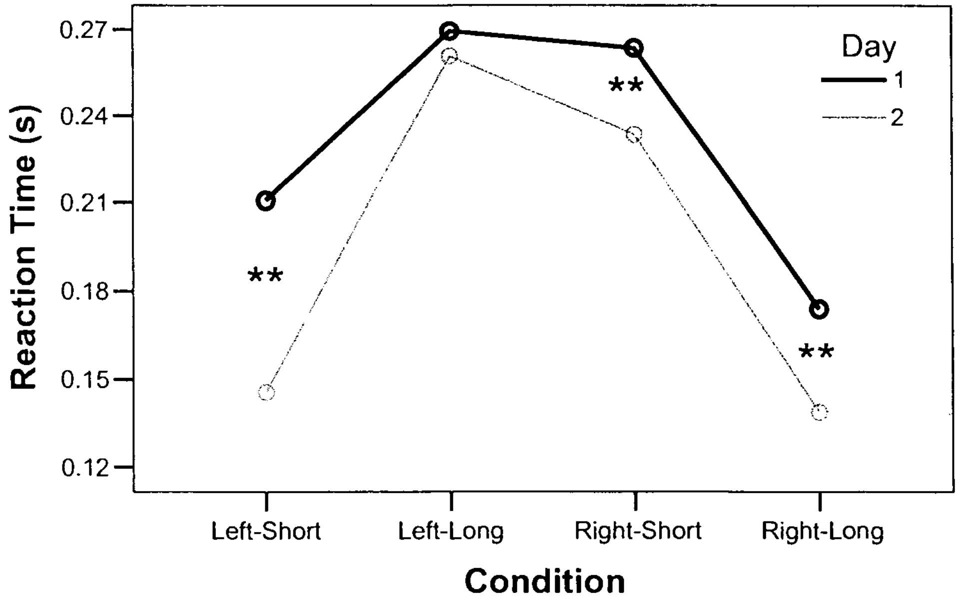


Figure 1. Graph of the Day x Condition interaction for reaction time. Asterisks indicate that reaction time was significantly ($p < .01$) faster on Day 2 than Day 1 for all conditions except for the Left-Long condition.

Table 6

Means (M) and Standard Deviations (SD) for Movement Time Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M (s)	.208	.260	.210	.264	.236	.196	.247	.214	.250	.227
SD	.028	.026	.030	.029	.038	.034	.036	.034	.038	.041
Less Fit (n=7)										
M (s)	.241	.327	.256	.322	.286	.240	.329	.246	.324	.285
SD	.100	.112	.113	.100	.111	.077	.100	.077	.099	.096
Both Groups (n=14)										
M (s)	.225	.293	.233	.293	.261	.218	.288	.230	.287	.256
SD	.074	.087	.085	.078	.086	.063	.085	.061	.082	.079

Table 7

Means (M) and Standard Deviations (SD) for Movement Time Nested by Days and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Day 1					
M (s)	.225	.293	.233	.293	.261
SD	.074	.087	.085	.078	.086
Day 2					
M (s)	.218	.288	.230	.287	.256
SD	.063	.085	.061	.082	.079
Both Days					
M (s)	.221	.291	.232	.290	.258
SD	.068	.085	.073	.080	.083

Table 8

Group x Day x Condition Repeated Measures Analysis of Variance for Movement Time

Source	*df*	SS	MS	*F*	*p*
Group	1	.083	.083	2.20	.1635
Subject					
G x S (error)	12	.452	.038		
Day	1	.000	.000	0.45	.5153
Group x Day	1	.000	.000	0.21	.6529
G x S x D (error)	12	.022	.002		
Condition	3	.116	.039	80.44	.0000*
Group x Condition	3	.007	.002	4.79	.0066*
G x S x C (error)	36	.017	.000		
Day x Condition	3	.000	.000	0.10	.9612
Group x Day x Condition	3	.001	.000	1.09	.3666
GxSxDxC (error)	36	.012	.000		
Total	111	.713			
Grand Mean	1	7.47			

*Statistically significant, α < .05

Table 9

Means (M) and Standard Deviations (SD) for Movement Time Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (s)	.202[a]	.253[b]	.212[c]	.257[d]	.231
SD	.031	.031	.031	.034	.040
Less Fit Group (n=7)					
M (s)	.241	.328	.251	.323	.285
SD	.088	.104	.100	.098	.103
Both Groups (n=14)					
M (s)	.221	.291	.232	.290	.258
SD	.068	.085	.073	.080	.083

[a] Pairwise comparison to Less Fit group, $p = .287$. [b] Pairwise comparison to Less Fit group, $p = .092$.
[c] Pairwise comparison to Less Fit group, $p = .299$. [d] Pairwise comparison to Less Fit group, $p = .115$.

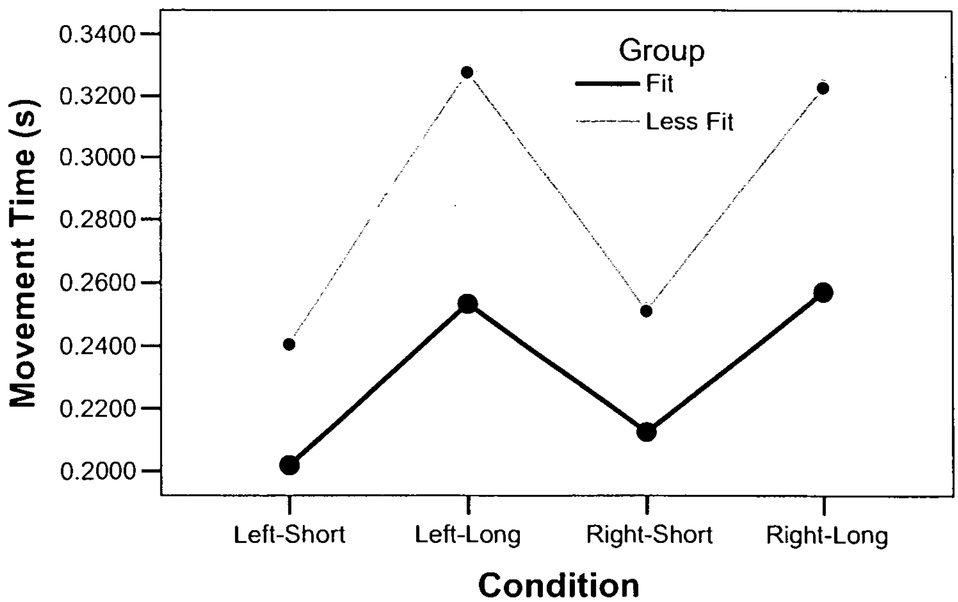


Figure 2. Graph of the significant Group x Condition interaction for movement time. There were no significance differences between Groups for any Condition, but visual inspection and *p*-values (see text) suggest that the Fit Group performed faster on the longer movements compared to the Less Fit Group.

significant (p = .0000), however, this finding was confounded by a significant Group x Condition interaction [$F(3,36) = 4.79$, $p = .0066$].

In order to identify the source of the Group x Condition interaction (see Figure 2), simple main effects with pairwise comparisons were done to compare the differences between Fit and Less Fit groups for each condition. The pairwise comparisons (see Table 9) failed to locate definitively the source of this interaction. These data, however, as illustrated in Figure 2, reveal a tendency for the Fit group to be faster than the Less Fit group for the long movements.

Response Time

Means and standard deviations for response time are presented in Tables 10 and 11, and ANOVA results are presented in Table 12. The Fit group (M = 416 ms, SD = 88) had a smaller mean response time than the Less Fit group (M = 524 ms, SD = 150), but this result fell short of statistical significance [$F(1,12) = 4.26$, $p = .061$]. There was a statistically significant interaction for the Day x Condition effect [$F(3,36) = 5.08$, p = .0049].

In order to further evaluate this Day x Condition interaction, simple main effects with pairwise comparisons were done to compare the Day 1 and Day 2 differences for each condition (see Table 13). Table 13 and Figure 3 reveal that Left-Short and Right-Long conditions were significantly faster on Day 2 than on Day 1. The other two conditions were not significantly faster on Day 2, although the Right-Short condition approached statistical significance (p = .06). In summary, the Left-Short and Right-Long conditions demonstrated a faster time on Day 2 as compared to Day 1. The Left-Long and Right-Short movements were not statistically different between Days 1 and 2. Overall,

Table 10

Means (M) and Standard Deviations (SD) for Response Time Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M (s)	.389	.488	.449	.415	.435	.318	.481	.426	.362	.397
SD	.047	.064	.050	.054	.064	.075	.104	.075	.077	.103
Less Fit (n=7)										
M (s)	.481	.638	.545	.515	.545	.409	.616	.501	.488	.504
SD	.133	.172	.142	.124	.152	.106	.149	.106	.151	.147
Both Groups (n=14)										
M (s)	.435	.563	.497	.465	.490	.363	.548	.464	.425	.450
SD	.109	.148	.115	.107	.128	.101	.144	.098	.134	.137

Table 11

Means (M) and Standard Deviations (SD) for Response Time Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (s)	.353	.484	.438	.389	.416
SD	.071	.085	.064	.071	.088
Less Fit Group (n=7)					
M (s)	.445	.627	.523	.502	.524
SD	.124	.158	.125	.136	.150
Both Groups (n=14)					
M (s)	.399	.556	.480	.445	.470
SD	.110	.145	.107	.122	.134

Table 12

Group x Day x Condition Repeated Measures Analysis of Variance for Response Time

Source	*df*	SS	MS	*F*	*p*
Group	1	.330	.330	4.26	.0613
Subject					
G x S (error)	12	.929	.077		
Day	1	.044	.044	11.98	.0047*
Group x Day	1	.000	.000	0.01	.9292
G x S x D (error)	12	.045	.004		
Condition	3	.368	.123	54.83	.0000*
Group x Condition	3	.013	.005	2.00	.1311
G x S x C (error)	36	.081	.002		
Day x Condition	3	.128	.004	5.08	.0049*
Group x Day x Condition	3	.002	.000	0.97	.4176
GxSxDxC (error)	36	.030	.000		
Total	111	1.85			
Grand Mean	1	24.7			

*Statistically significant at $\alpha = .05$

Table 13

Means (M) and Standard Deviations (SD) for Response Time Nested by Days and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Day 1					
M (s)	.435	.563	.497	.465	.490
SD	.109	.148	.115	.107	.128
Day 2					
M (s)	.363[a]	.548[b]	.464[c]	.425[d]	.450
SD	.101	.144	.098	.134	.137
Both Days					
M (s)	.399	.556	.480	.445	.470
SD	.110	.145	.107	.122	.134

[a] Pairwise comparison to Day 1, $p = .0001$ [b] Pairwise comparison to Day 1, $p = .429$
[c] Pairwise comparison to Day 1, $p = .06$. [d] Pairwise comparison to Day 1, $p = .012$.

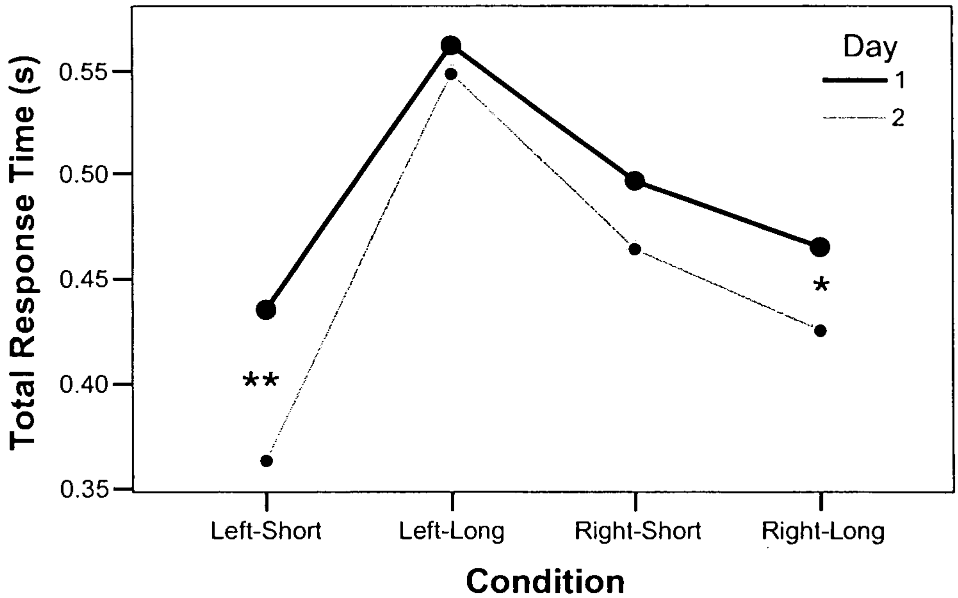


Figure 3. Graph of the Day x Condition interaction for response time. Asterisks indicate significant Day differences at $p < .05$ (*) and $p < .01$ (**)

the Fit group appeared to have faster response times than the Less Fit group, but this effect did not reach statistical significance.

Acceleration

Means and standard deviations for acceleration are presented in Table 14 and ANOVA results are presented in Table 15. There was a statistically significant Group x Condition interaction [$F(3,36) = 4.64$, $p = .0077$] and a significant Day x Condition interaction [$F(3,36) = 3.01$, $p = .0425$].

In order to identify the source of both the Group x Condition interaction and the Day x Condition interaction for acceleration, simple main effects with pairwise comparisons were conducted for both interactions. For the Day x Condition interaction, Table 16 reports and Figure 4 illustrates, that all Conditions were the same for Day 1 and Day 2, except for a nearly significant ($p = .06$) effect suggesting that Day 2 was faster than Day 1. For the Group x Condition interaction, Table 17 and Figure 5 show that the Fit Group was significantly faster for the longer movements. Further, while not statistically significant, the Fit group was 24% faster overall for the Left-Short and Right-Short movements.

In summary, the post hoc analyses failed to pinpoint the source of the Day x Condition interaction. Inspection of Figure 4 and the p-values for the pairwise comparisons, however, suggest that there was a tendency for the movements to the left to be faster on Day 2 compared to Day 1. Post hoc tests and Figure 5 revealed that the Fit group had a faster acceleration than the Less Fit group, but these faster accelerations were only significantly faster in the longer movements.

Table 14

Means (M) and Standard Deviations (SD) for Acceleration Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M (au)	.619	.840	.618	.788	.716	.711	.916	.654	.771	.763
SD	.161	.205	.202	.199	.212	.206	.207	.212	.183	.220
Less Fit (n=7)										
M (au)	.481	.564	.434	.526	.501	.565	.606	.486	.576	.558
SD	.185	.220	.174	.192	.195	.255	.259	.229	.251	.246
Both Groups (n=14)										
M (au)	.550	.702	.526	.657	.609	.638	.761	.570	.674	.661
SD	.184	.252	.207	.234	.230	.239	.279	.233	.237	.253

Note: Acceleration is measured in arbitrary units (au).

Table 15

Group x Day x Condition Repeated Measures Analysis of Variance for Acceleration

Source	*df*	SS	MS	*F*	*p*
Group	1	1.24	1.24	5.29	.0402*
Subject					
G x S (error)	12	2.82	.235		
Day	1	.077	.077	1.86	.1977
Group x Day	1	.000	.000	0.01	.9111
G x S x D (error)	12	.498	.042		
Condition	3	.544	.181	28.79	.0000*
Group x Condition	3	.088	.029	4.64	.0077*
G x S x C (error)	36	.227	.006		
Day x Condition	3	.020	.007	3.01	.0425*
Group x Day x Condition	3	.010	.003	1.53	.2235
GxSxDxC (error)	36	.079	.002		
Total	111	5.60			
Grand Mean	1	45.2			

*Statistically significant at $\alpha = .05$

Table 16

Means (M) and Standard Deviations (SD) for Acceleration Nested by Days and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Day 1					
M (arb.units)	.550	.702	.526	.657	.609
SD	.184	.252	.207	.234	.229
Day 2					
M (arb.units)	.638[a]	.761[b]	.570[c]	.674[d]	.661
SD	.239	.279	.233	.237	.254
Both Days					
M (arb.units)	.594	.732	.548	.665	.635
SD	.216	.265	.220	.234	.243

Note: Acceleration is measured in arbitrary units (arb. units).
[a] Pairwise comparison to Day 1, $p = .06$. [b] Pairwise comparison to Day 1, $p = .120$
[c] Pairwise comparison to Day 1, $p = .357$. [d] Pairwise comparison to Day 1, $p = .697$.

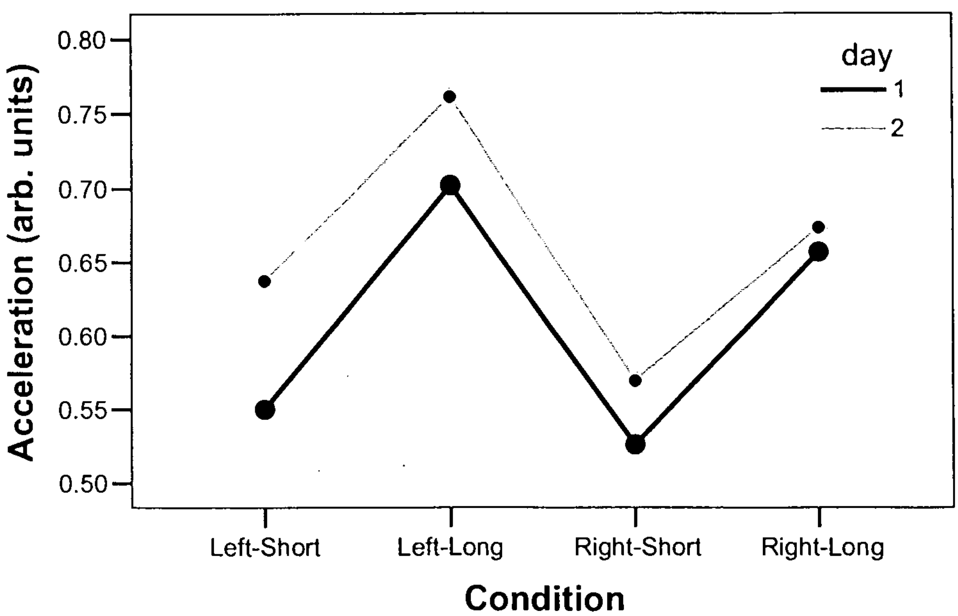


Figure 4. Graph of the significant Day x Condition interaction for acceleration. There was a nearly significant ($p = .06$) difference between Days for the Left-Short condition.

Table 17

Means (M) and Standard Deviations (SD) for Acceleration Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (arb. units)	.665 [a]	.878 [b]	.635 [c]	.780 [d]	.740
SD	.187	.206	.204	.188	.216
Less Fit Group (n=7)					
M (arb. units)	.523	.585	.460	.551	.530
SD	.223	.237	.201	.221	.223
Both Groups (n=14)					
M (arb. units)	.594	.732	.548	.665	.635
SD	.216	.265	.220	.234	.243

Note: Acceleration is measured in arbitrary units (arb. units)
[a] Pairwise comparison to Less Fit group, $p = .160$. [b] Pairwise comparison to Less Fit group, $p = .018$.
[c] Pairwise comparison to Less Fit group, $p = .063$. [d] Pairwise comparison to Less Fit group, $p = .03$.

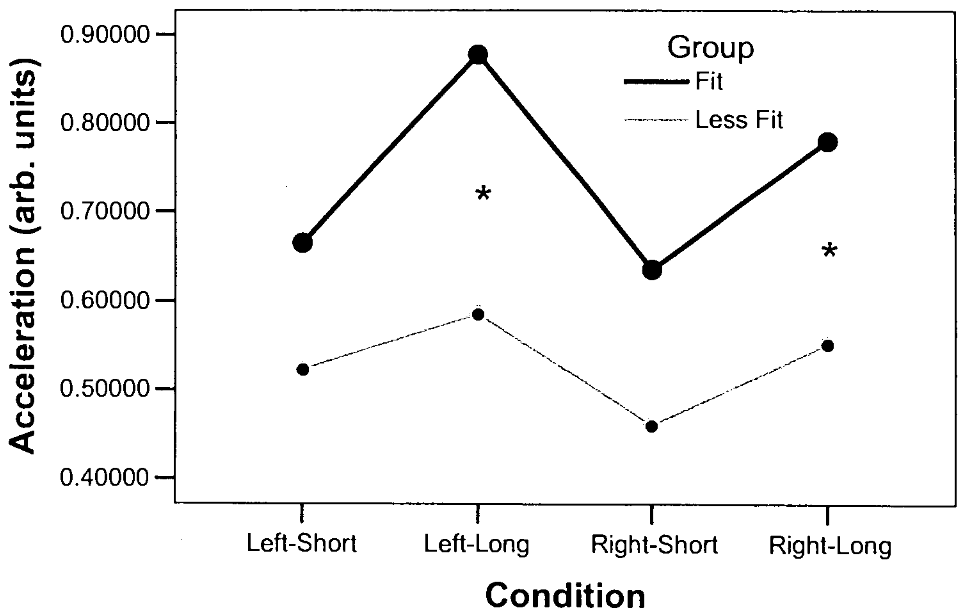


Figure 5. Graph of the Group x Condition interaction for acceleration. Asterisks (*) indicate significant ($p < .05$) differences between Groups for the long movement conditions.

Negative Acceleration

Means and standard deviations for negative acceleration are presented in Tables 18 and 19, and ANOVA results are presented in Table 20. A statistically significant interaction was found for the Group x Condition effect [$F(3,36) = 4.10, p = .0133$].

In order to identify the source of the Group x Condition interaction, simple main effects with pairwise comparisons were compiled to examine the differences between groups for each condition (Table 21). No significant pairwise comparisons emerged, but visual inspection of Figure 6, and nearly significant p-values (Table 21) suggest that the Fit group demonstrated better negative acceleration, especially in the movements to the right.

Accuracy

Means and standard deviations for Accuracy are presented in Tables 22 and 23, and ANOVA results are presented in Table 24. No statistically significant interactions were revealed, however, there was a main effect for Condition [$F(3,36) = 9.99, p = .0001$]. Post hoc contrasts (see Table 23, Figure 7) were calculated to examine which conditions differed from one another. Based upon this analysis, the Left-Long movement demonstrated significantly ($p < .01$) worse accuracy than the Right-Short, Left-Short, and Right-Long movements.

Summary

In summary, the Fit Group possessed significantly greater maximal oxygen consumption, a significantly stronger one repetition maximum bench press and a significantly lower resting systolic blood pressure than the Less Fit Group. The Fit Group was significantly faster for movement time and exhibited a significantly greater

Table 18

Means (M) and Standard Deviations (SD) for Negative Acceleration Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M au)	.832	1.026	1.104	1.275	1.059	.936	1.060	1.122	1.363	1.120
SD	.351	.469	.436	.614	.491	.517	.498	.516	.769	.591
Less Fit (n=7)										
M (au)	.612	.624	.672	.747	.664	.665	.733	.756	.861	.754
SD	.264	.293	.310	.337	.299	.326	.373	.355	.416	.366
Both Groups (n=14)										
M (au)	.722	.825	.888	1.011	.862	.800	.897	.939	1.118	.937
SD	.325	.435	.432	.555	.451	.446	.463	.473	.658	.523

Note: Acceleration is measured in arbitrary units (au).

Table 19

Means (M) and Standard Deviations (SD) for Negative Acceleration Nested by Days and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Day 1					
M (arb. units)	.722	.825	.888	1.011	.862
SD	.325	.435	.432	.555	.451
Day 2					
M (arb. units)	.800	.897	.939	1.112	.937
SD	.446	.463	.473	.658	.523
Both Days					
M (arb. units)	.761	.861	.913	1.061	.899
SD	.389	.446	.449	.605	.488

Note: Acceleration is measured in arbitrary units (arb. units)

Table 20

Group x Day x Condition Repeated Measures Analysis of Variance for Negative Acceleration

Source	*df*	SS	MS	*F*	*p*
Group	1	4.06	4.06	3.15	.1011
Subject					
G x S (error)	12	15.4	1.29		
Day	1	.158	.158	1.20	.2939
Group x Day	1	.006	.006	.050	.8334
G x S x D (error)	12	1.57	.131		
Condition	3	1.32	.440	20.9	.0000*
Group x Condition	3	.259	.086	4.10	.0133*
G x S x C (error)	36	.759	.021		
Day x Condition	3	.009	.003		
Group x Day x Condition	3	.017	.006	.510	.6761
GxSxDxC (error)	36	.210	.006		
Total	111	23.8			
Grand Mean	1	90.6			

*Statistically significant at α = .05

Table 21

Means (M) and Standard Deviations (SD) for Negative Acceleration Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (arb. units)	.884[a]	1.043[b]	1.113[c]	1.319[d]	1.089
SD	.437	.475	.470	.684	.542
Less Fit Group (n=7)					
M (arb. units)	.638	.679	.714	.804	.709
SD	.292	.334	.330	.376	.335
Both Groups (n=14)					
M (arb. units)	.761	.861	.913	1.061	.899
SD	.389	.446	.449	.605	.488

Note: Acceleration is measured in arbitrary units (arb. units).
[a] Pairwise comparison to Less Fit group, p = .206. [b] Pairwise comparison to Less Fit group, p = .107.
[c] Pairwise comparison to Less Fit group, p = .069. [d] Pairwise comparison to Less Fit group, p = .085.

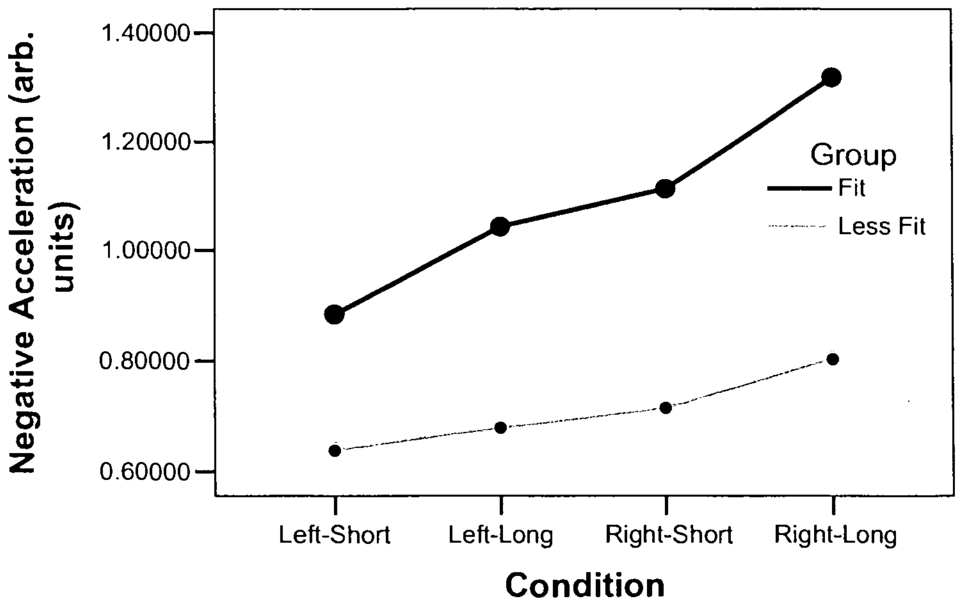


Figure 6. Graph of the Group x Condition interaction for negative acceleration. Post hoc tests failed to precisely locate the source of the interaction.

Table 22

Means (M) and Standard Deviations (SD) for Accuracy Nested by Groups, Conditions, and Days

	Day 1 Conditions					Day 2 Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean	Left Short	Left Long	Right Short	Right Long	Mean
Fit (n=7)										
M (deg)	-3.77	-5.23	-2.36	-3.23	-3.65	-2.78	-4.65	-2.03	-3.54	-3.25
SD	1.04	1.08	1.29	1.97	1.72	1.17	0.95	1.44	1.69	1.63
Less Fit (n=7)										
M (deg)	-3.46	-5.27	-3.02	-3.66	-3.85	-2.66	-3.42	-2.33	-2.57	-2.75
SD	3.18	5.61	3.60	5.93	4.68	2.00	3.02	2.64	3.50	2.78
Both Groups (n=14)										
M (deg)	-3.61	-5.25	-2.69	-3.45	-3.75	-2.72	-4.04	-2.18	-3.06	-3.00
SD	2.33	3.97	2.67	4.34	3.51	1.61	2.28	2.09	2.71	2.25

Table 23

Means (M) and Standard Deviations (SD) for Accuracy Nested by Groups and Conditions

	Conditions				
	Left Short	Left Long	Right Short	Right Long	Mean
Fit Group (n=7)					
M (deg)	-3.27	-4.94	-2.19	-3.39	-3.45
SD	1.20	1.04	1.35	1.80	1.68
Less Fit Group (n=7)					
M (deg)	-3.06	-4.34	-2.68	-3.12	-3.30
SD	2.64	4.52	3.12	4.80	3.88
Both Groups (n=14)					
M (deg)	-3.16	-4.64**	-2.43	-3.25	-3.37
SD	2.03	3.26	2.39	3.59	2.98

** Left-Long condition significantly different from the other conditions, $p < .01$

Table 24

Group x Day x Condition Repeated Measures Analysis of Variance for Accuracy

Source	*df*	SS	MS	*F*	*p*
Group	1	.709	.709	0.01	.9061
Subject					
G x S (error)	12	585.0	48.8		
Day	1	15.5	15.4	3.93	.0707
Group x Day	1	3.72	3.72	0.95	.3494
G x S x D (error)	12	47.1	3.93		
Condition	3	71.3	23.8	9.99	.0001*
Group x Condition	3	4.42	1.47	0.62	.6075
G x S x C (error)	36	85.7	2.38		
Day x Condition	3	2.89	.962	1.76	.1725
Group x Day x Condition	3	2.79	.932	1.70	.1839
GxSxDxC (error)	36	19.7	.547		
Total	111	839.8			
Grand Mean	1	1277.9			

*Statistically significant at $\alpha = .05$

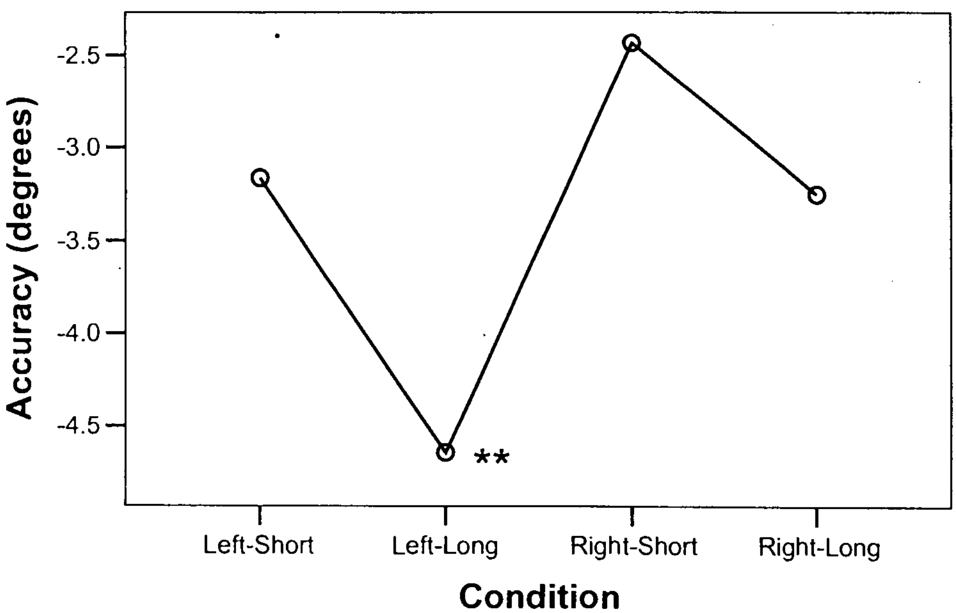


Figure 7. Graph of the Condition effect for accuracy. ** The Left-Long condition was significantly less accurate than the other conditions, $p < .01$.

acceleration than the Less Fit Group. The likely source of these statistically significant differences is the longer movements. While the Fit Group demonstrated a 23% faster mean reaction time and a 35% greater mean negative acceleration than the Less Fit Group, these findings failed to reach statistical significance. The Group x Condition interaction was statistically significant for negative acceleration, albeit the source of this interaction could not be determined. There was no significant difference between groups for accuracy.

Chapter 5

DISCUSSION

The purpose of this experimentation was to conduct an analysis of motor coordination in young adult males based on their cardiovascular fitness. Through the use of a complex motor task performed in the standing position, data obtained revealed that fit young adult males demonstrate better motor coordination in movement time and acceleration than less fit young adult males. While the anticipation timing accuracy between the two groups revealed that the groups were equally accurate in the motor task, the overall finding of this study is that the fit group was able to perform the motor tasks faster than the less fit group without forfeiting accuracy.

Analysis of the subject characteristics revealed that the grouping of the subjects into Fit and Less Fit was successful (see Table 1 for reference). Groups were comparable in age, height, weight and body composition data. As mentioned previously, the subjects in the study were grouped according to their VO2 max data, which statistically resulted in the Fit Group possessing a significantly greater VO2 max than the Less Fit Group. Subjects in the Fit group also exhibited significantly greater bench press strength to weight ratio and a non-significant stronger handgrip over the Less Fit group.

This poses an interesting dilemma in terms of the interpretation of these data. Considering that prior studies revealed both cardiovascular and strength training can improve psychomotor control (Christensen et al., 2003), albeit in the elderly, there is a question of whether the results of this experiment are due to cardiovascular fitness, strength, or a combination of both. While this study did not attempt to differentiate between cardiovascular and strength data, the grouping of the subjects was based upon the VO2 max data, which resulted in a statistically significant difference between the groups.

The results of this study revealed that the Fit group demonstrated significantly decreased movement time and a significantly greater acceleration over the Less Fit group. This supports the hypothesis that there are measurable psychomotor differences between young adults based upon fitness level (Hillman, Weiss, Hagberg, & Hatfield, 2002).

As far as the speed of the movements is concerned, the Fit group was clearly faster than the Less Fit group. Reaction times, while not statistically significant, were overall 23% faster in the Fit group. Further, the Fit group was faster (19%) than the Less Fit group in movement time, and these results were statistically significant in the longer movements. The main difference between the movement times and the reaction times is that the reaction time is a measure of the cognitive processing (Donchin & Coles, 1988), while the movement time is the actual measure of the physical response (Schmidt, 1982).

The 23% faster reaction times in the Fit group are similar to results from research conducted on the elderly. Study after study has shown that physical activity in the elderly population can improve reaction times (Clarkson, 1978; Clarkson & Kroll, 1978; Rotella & Bunker, 1978; Smith & Green, 1962; Spirduso, 1975; Spirduso & Clifford, 1978). Though not statistically significant in this study, there is enough data to show a tendency for better reaction times in fit individuals of the young adult population.

As for movement time, the Fit group demonstrated significantly better movement time than the Less Fit group. More specifically, the results imply that the measurable difference between the groups was discovered in the longer movements, as opposed to the shorter movements. This supports the hypothesis by Kerr and Boucher (1992) that more complex movements may be required to draw out motor coordination differences between younger subject populations. In this case, the longer movements required not just a longer movement distance, but also greater total body coordination by the subjects.

The significance of the findings on movement time is that the Fit group was able to accomplish the task faster than the Less Fit group as a result of this motor coordination advantage. This finding complies with the vast amount of research on both athletes (Beitel & Kuhlman, 1989, 1992; Mokha et al., 1992) and the elderly, (Clarkson, 1978; Rotella & Bunker, 1978; Spirduso, 1975; Spirduso & Clifford, 1978), suggesting that through exercise training, the speed of movements can be increased. In this study, the movement was a novel activity to all subjects and all subjects were required to undergo the same number of trials, so there would be no independent training influence. Thus, the assumed reason for the increased movement speed is the influence of habitual physical activity in the Fit group. Therefore, even in a young adult population, there is the potential through participation in regular exercise, to improve the speed of movement.

The same types of results were present for the force component of movement. The Fit group possessed a significantly faster acceleration than the Less Fit group. Further, albeit not statistically significant, the Fit group had a 35% better negative acceleration than the Less Fit group. Though there was a significant Group x Condition interaction for negative acceleration, the source of this interaction was unable to be discovered. Since acceleration is an indicator of force, the results indicate that the Fit group is capable of exerting more force through the movement, which may enable the movement to be accomplished faster. Importantly, the results do indicate, as was seen in the movement time data, that the source of the difference between groups for acceleration was likely in the longer movements. Again, this supports the hypothesis by Kerr and Boucher (1992) that more complex movements may be required to bring out motor coordination differences between younger subject populations.

An issue with the acceleration data, and indirectly the movement time data, is whether the source of the acceleration difference is due to the subject's cardiovascular capacity or due to strength. Research conducted on young adults (aged 21-35 years) showed that with a four week resistance training program, the rate of force development increased by 25% (Barry, Warman, & Carson, 2005). This means that after only a month of resistance training, a substantial increase in force can be attained. Since acceleration is an indicator of force, and since an individual's strength may impact the acceleration, an argument could be made that the reason for the increased acceleration of the Fit group was due to the Fit group's greater strength, as opposed to the cardiovascular capacity. Due to the nature of this study, it is impossible to determine the actual source of this acceleration increase. Regardless, it is evident that the overall fitness level of the Fit group, according to both cardiovascular and strength data, may have contributed a psychomotor benefit compared to the Less Fit group. This hypothesis is in accordance with current research on this topic (Christensen et al., 2003; Hatta et al., 2005; McMorris, Delves, Sproule, Lauder, & Hale, 2005).

Accuracy of anticipation timing, by itself, really did not reveal differences between the groups. However, some interesting observations can be made when looking at the overall significance of this accuracy data. It can be speculated that the subjects in both groups were capable of completing the given tasks with the same degree of accuracy. Therefore, this study would imply that regardless of the young adults' level of fitness, the ability to accomplish this component of the psychomotor task is consistent regardless of level of fitness. The fact that the accuracy was basically the same follows because young adults are not burdened by the degenerative changes of old age that can impact accuracy (Sparrow, Parker, Brendan, & Wengier, 2005). Perhaps most revealing, however, is the interaction between speed and accuracy and force and accuracy. Generally, accuracy suffers with increased speed or force, but the faster Fit group did not have worse accuracy. The Fit group was able to accomplish the task, in particular the longer movements, with greater speed and force but with no loss of accuracy. As speed is a component of the force of the movement, the Fit group was capable of exerting and controlling a greater degree of force to accomplish the task quicker than the Less Fit group (Kawabe-Himeno, 1991; Newell et al., 1980).

The main question that comes out of this study is the following: Since there is evidence that even young adults can exhibit better motor coordination through fitness, what is the mechanism for this better coordination? There is much research that suggests that the pathway responsible for better motor coordination for fit subjects would be a physiological advantage due to increased oxygen consumption and the ability to deliver oxygen more effectively to the neuromuscular sites that control movement (Doherty, 1993; Doherty et al., 1993; Dustman et al., 1984; Spirduso, 1982). While this is likely a contributing factor, current research in the field of neuroscience has set forth evidence of actual neurological enhancements to the brain as a result of habitual exercise (Colcombe & Kramer, 2003).

This evidence suggests that when motor tasks are habitually conducted through exercise and physical activities, the motor regions in the brain and the neurological pathways change and adapt to these movements. Therefore, an increased level of physical fitness may not only advance motor coordination through increased cardiovascular and strength capacity in young adults, but also through neurological enhancement (Hatta et al., 2005). Only speculations can be made based upon the research in this study as to what are the causes of these results, but the fact that motor coordination differences were detectable in the young adult populations opens up the possibility that with the right experimental conditions, neurological enhancements are feasible and may be detectable.

Examining these data in light of the compendium of research conducted in the field of motor coordination, there is one interesting result that bears mentioning. Previously, there was some discussion on Fitts Law, the speed/accuracy tradeoff. One would expect, based upon this theory, that by increasing the speed of the task, the accuracy would be compromised to some degree. However, it is interesting, that the reaction time data indicates that the long movement to the left consistently demonstrated a longer reaction time than the other movements, while the movement time was comparable to the long movement to the right. Further, the reaction time for the long movement to the left did not significantly change from Day 1 to Day 2. What makes this interesting is that in regards to accuracy, the long movement to the left was the worst accuracy of all the movements. So, the question arises, why the task with the longest reaction time, indicating the greatest mental processing, produced the worst accuracy? It may be the nature of that task, which was a movement across the body, was more difficult than the other three movements, or there may be an effect due to the cross over of cerebral hemispheres during the processing of this particular movement. Based upon the limits of this study, any attempt to answer this question would be mere speculation.

There is one final issue that needs to be addressed. During the analysis of the reaction time data, some reaction times were noted less than 100 milliseconds. While there is the inherent risk of subject anticipation in such studies, the number of abnormally fast reaction times warranted mentioning. The testing apparatus was inspected for a potential internal delay, but no mechanical defects were discovered. While the reaction time data is probably accurate, this researcher advises caution in relying upon the reaction time and response time data. If there was an internal delay, such delay would not affect the remaining variables of movement time, acceleration, negative acceleration and accuracy.

In conclusion, there is evidence from this study, which is supported by past research, that cardiovascular fitness, and possibly greater muscle strength, may be an indicator of increased motor coordination even in young adults. While the exact pathways facilitating the increased psychomotor performance are undetermined, it is speculated that fit individuals possess better motor coordination, mentally and physically, resulting in greater speed and force in accomplishing a complex motor task. Interestingly, the overall accuracy of the movements did not differ significantly based on fitness level, emphasizing that young adults, regardless of fitness level, possess a consistent degree of proficiency in conducting a motor task.

Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overall, the fit young adults exhibited better motor control than their less fit counterparts. Specifically, while the groups were comparable in accuracy, the Fit group demonstrated faster speed and greater force during the movements than the Less Fit group. This study confirms that motor coordination differences can be measured in young adults who are not athletes and that fitness level may influence motor coordination in the young adult population as it does in the elderly population.

Conclusions

This study concludes, in spite of research indicating the contrary, that motor coordination differences are measurable in young adults through the use of a complex motor task, as utilized in this study. The results indicate that the longer movements in this study allowed for the detection of significant differences in both speed and force between the fit and less fit groups. By simply increasing the complexity of the experimental condition to incorporate movements that involve greater body coordination, even differences in the younger populations are measurable.

Second, this study reveals that fitness plays a factor in enhancing motor coordination, which positively benefits the young adult population. In this study, the Fit group possessed a faster movement time and greater acceleration than the Less Fit group, which allowed the Fit group to accomplish the task faster than the Less Fit group with the same accuracy. This information implies that the overall fitness of young adults may impact their psychomotor and motor faculties and enhance their overall ability to accomplish a movement. Therefore, while the accuracy of the movements may be the same between the young adults because the effects of aging have not yet set in, the young adult population can obtain motor coordination benefits from enhanced cardiovascular fitness.

Recommendations For Further Study

In light of the many findings that were nearly statistically significant, and also the concern over the reaction time data, the obvious recommendation for further study is a follow up examination of this research study to attempt to validate and confirm the findings herein. In conducting a follow up study, it would be desirable to obtain a larger subject population in order to obtain subjects with lower VO2 max scores. In the present study, even the Less Fit group would have been considered average in regards to cardiovascular fitness. A sampling of subjects with lower VO2 max scores, if the findings of this study are accurate, would reveal an even greater statistical significance between the fit and less fit groups.

There is a question in this study of whether the Fit group's advantage over the Less Fit group is truly due to the Fit group's cardiovascular level (VO2 max), the Fit group's better strength, to a combination of both or even to genetics. A study is recommended to investigate cardiovascular versus strength in the young adult population and the impact each has on motor coordination. This could be accomplished through an experimental design study with longitudinal data. Such a study could be accomplished using the same motor task as described and used in this study. Four subject groups would be needed. After a baseline set of motor coordination tests have been conducted, the subjects could randomly be split into four groups. The first group would be a control group, the second group would participate in a strength training program, the third group would participate in a cardiovascular program and the fourth would participate in a combined cardiovascular/strength training program. After a set period of time, the groups would be tested again and the results would be compared to the initial set of tests. This type of experiment could offer insight into whether cardiovascular fitness or strength training contributes to motor coordination benefits in young adults.

Another study that is recommended is a correlation study between VO2 max data and motor coordination. Since there is evidence that VO2 max data is the best indicator of cardiovascular fitness, and since motor coordination can be increased by aerobic fitness, can VO2 max then be an indicator of motor coordination? A large group of subjects would be preferred for this type of correlation study. All of the subjects would be required to conduct a VO2 max test and then complete a round of motor coordination testing. These data could then be used to correlate VO2 max with motor coordination.

Finally, there was mention in this study about more recent research that indicates that neurological changes in the brain may occur with physical activity and the performance of motor tasks. In order to properly evaluate any neurological changes that may occur in young adults due to cardiovascular fitness, subjects would have to submit to fMRI testing. While such testing is not available everywhere, the benefits of this type of experimentation would be to provide a baseline study on young adults, which could not only impact this subject population, but could also provide data to be analyzed in conjunction with older subject populations in order to evaluate the lifelong impact of physical activity on the neurological system. It is understood at this point that increased exercise at any age leads to psychomotor benefits, which have been attributed to a more efficient system of oxygen delivery in the body. However, there must be an underlying neurological process that explains this phenomenon. Only the use of updated technology, such as fMRI tests, can help crack this mystery.

REFERENCES

American College of Sports Medicine. ACSM's guidelines for exercise testing and prescriptions. 6th Edition. Philadephia, PA: Lippincott, Williams & Wilkins, 2000.

Amunts, K., Schlung, G., Jancke, L., Steinmetz, H., Schliecher, A., Dabringhaus, A., & Zilles, K. (1997). Motor cortex and hand motor skills: Structural compliance in the human brain. Human Brain Mapping, 5, 206-215.

Annett, J. (1994). The learning of motor skills: Sports science and ergonomics perspectives. Ergonomics, 37, 5-16.

Arcelin, R., Delignieres, D., & Brisswalter, J. (1998). Selective effects of physical exercise on choice reaction processes. Perceptual and Motor Skills, 87, 175-185.

Ari, Z., Kutlu, N., Uyanik, B., Taneli, F., & Buyukyazi, G. (2004). Serum testosterone, growth hormone, and insulin-like growth factor-1 levels, mental reaction time, and maximal aerobic exercise in sedentary and long-term physically trained elderly males. International Journal of Neuroscience, 114, 623-637.

Astrand, P.O. (1956). Human physical fitness with special reference to sex and age. Physiological Review, 36, 307-355.

Asanuma, H., & Pavlides, C. (1997). Neurobiological basis of motor learning in mammals. Neurology Report, 8, i-vi.

Barry, K.B., Warman, G.E., & Carson, R.G. (2005). Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. Experimental Brain Research, 162, 122-132.

Bartke, A. (2005). Minireview: Role of the growth hormone/insulin-like growth factor system in mammalian aging. Endocrinology, 146, 3718-3723.

Beitel, P.A., & Kuhlman, J.S. (1992). Relationships among age, sex and depth of sport experience with initial open-task performance by 4 to 9 year-old children. Perceptual and Motor Skills, 74, 387-396.

Bhanot, J.L., & Sidhu, L.S. (1980). Reaction time of hockey players with reference to their field positions. Journal of Sports Medicine, 20, 423-430.

Birren, J.E. (1964). The psychology of aging. Englewood Cliffs, NJ: Prentice-Hall.

Booth, F.W., Weeden, S.H., & Tseng, B.S. (1994). Effect of aging on human skeletal muscle and motor function. Medicine and Science in Sports and Exercise, 26, 556-560.

Botwinick, J.E., & Thompson, L.W. (1978). Age differences in reaction time: An artifact? Gerontologist, 8, 25-28.

Brown, W.F. (1972). A method for estimating the number of motor units in thenar muscles and the change in motor unit count with aging. Journal of Neurology, Neurosurgery and Psychiatry, 35, 845-852.

Burley, L.R. (1944). A study of the reaction time of physically trained men. Research Quarterly, 15, 232-239.

Burpee, R.H., & Stroll, W. (1936). Measuring reaction times of athletes. Research Quarterly, 7, 110-118.

Campbell, M.J., McComas, A.J., & Petito, F. (1973). Physiological changes in aging muscle. Journal of Neurology, Neurosurgery and Psychiatry, 36, 174-182.

Canadian Society for Exercise Physiology. PAR-Q and You. Gloucester, Ontario: Canadian Society for Exercise Physiology, 1994.

Charlton, C., Ridding, M., Thompson, P., & Miles, T. (2003). Prolonged peripheral nerve stimulation induces persistent changes in excitability of human motor cortex. Journal of the Neurological Sciences, 208, 79-85.

Christensen, C., Payne, G., Wughalter, E., Yan, J., Hanenhan, M., & Jones, R. (2003). Physical activity, physiological, and psychomotor performance: A study of variously active older adult men. Research Quarterly for Exercise and Sport, 74, 136-142.

Clarkson, P.M. (1978). The effect of age and activity level on simple and choice fractionated response time. European Journal of Applied Physiology, 40, 17-25.

Clarkson, P.M., & Kroll, W. (1978). Practice effects on fractionated response time related to age and activity level. Journal of Motor Behavior, 10, 275-286.

Clarkson, P.M., Kroll, W., & Melchionda, A.M. (1981). Age, isometric strength, rate of tension development and fiber type composition. Journal of Gerontology, 36, 648-653.

Classen, J., Leipert, J., Wise, S., Hallett, M., & Cohen, L. (1998). Rapid plasticity of human cortical movement representation induced by practice. Journal of Neurophysiology, 79, 1117-1123.

Colcombe, S., & Kramer, A. (2003). Fitness effect on the cognitive function of older adults: A meta-analysis study. Psychological Science, 14, 125.

Collet, C. (1999). Strategic aspects of reaction time in world-class sprinters. Perceptual and Motor Skills, 88, 65-77.

Cote, I., Salmela, J., & Papathanasopoulu, K.P. (1992). Effects of progressive exercise on attentional focus. Perceptual and Motor Skills, 75, 351-354.

Cureton, T.K. (1951). Physical fitness of champion athletes. Urbana: University of Illinois Press.

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2006). Physical exercise facilitates motor processes in simple reaction time performance: An electromyographic analysis. Neuroscience Letters, 396, 54-56.

Davranche, K., & Audiffren, M. (2004). Facilitating effects of exercise on information processing. Journal of Sports Sciences, 22, 419-428.

Davranche, K., Audiffren, M., & Denjean, A. (2006). A distributional analysis of the effect of physical exercise on a choice reaction time task. Journal of Sports Science, 24, 323-329.

D'Esposito, M., Zarahn, E., Aguirre, G.K., & Rypma, B. (1999). The effect of normal aging on the coupling of neural activity to the bold hemodynamic response. Neuroimaging, 20, 6-14.

Dik, M., Pluijm, S., Jonker, C., Deeg, D., Lomecky, M., & Lips, P. (2003). Insulin-like growth factor I and cognitive decline in older persons. Neurobiology of Aging, 24, 573-581.

Doherty, T.J. (1993). Age-related changes in the numbers and physiological properties of the human motor units. Doctoral dissertation, The University of Western Ontario.

Doherty, T.J., Vandervoort, A.A., & Brown, W.F. (1993). Effects of aging on the motor unit: A brief review. Canadian Journal of Applied Physiology, 18, 331-358.

Donchin, E., & Coles, M.G.H. (1988). Is the P300 component a manifestation of context updating? Behavioral and Brain Science, 11, 357-374.

Donders, F.C. (1868). On the speed of mental processes. Acta Physiologica, 30, 412-431.

Dustman, R.E., Ruhling, R.O., Russell, E.M., Shearer, D.E., Bonekat, H.W., Shigeoka, J.W., Wood, J.S., & Bradford, D.C. (1984). Aerobic exercise training and improved neuropsychological functioning of older individuals. Neurobiology of Aging, 5, 35-42.

Elbel, E.R. (1940). A study of response time before and after strenuous exercise. Research Quarterly, 11, 133-142.

Engelhorn, R. (1997). Speed and accuracy in the learning of a complex motor skill. Perceptual and Motor Skills, 85, 1011-1017.

Era, P., Jokela, J., & Heikkinen, E. (1986). Reaction and movement times in men of different ages: A population study. Perceptual and Motor Skills, 63, 111-130.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47, 381-391.

Fleishman, E., Quaintance, M., & Broedling, L. (1984). Taxonomies of human performance: the description of human performance. Orlando: Academic Press.

Forth, C.D., & Salmoni, A.W. (1988). Relationships among self-reported physical activity, aerobic fitness and reaction time. Canadian Journal of Sports Science, 13, 1, 88-90.

Foster, T., Sharrow, K., Kumar, A., & Masse, J. (2003). Interaction of age and chronic estradiol replacement on memory and markers of brain aging. Neurobiology of Aging, 24, 839-852.

Fowler, B., Taylor, M., & Porlier, G. (1987). The effects of hypoxia on reaction time and movement time components of a perceptual-motor task. Ergonomics, 30, 1475-1485.

Frischknecht, R. (1998). Effect of training on muscle strength and motor function in the elderly. Reproduction and Nutritional Development, 38, 167-74.

Gauchard, G., Tessier, A., Jeandel, C., & Perrin, P. (2003). Improved muscle strength and power in elderly exercising regularly. International Journal of Sports Medicine, 24, 71-74.

Gerloff, C., Corwell, B., Chen, R., Hallett, M., & Cohen, L. (1998). The role of the human motor cortex in the control of complex and simple finger movement sequences. Brain, 121, 1695-1709.

Gollnick, P.D., Armstrong, R.B., Sanbert, C.W., Piehl, K., & Saltin, B. (1972). Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. Journal of Applied Physiology, 33, 312-319.

Grimby, G., & Saltin, B. (1983). The aging muscle. Clinical Physiology, 3, 209-218.

Hakkinen, K., Pastinen, U.M., Karsikas, R., & Lannimo, V. (1995). Neuromuscular performance in voluntary bilateral and unilateral contractions and during electrical stimulation in men at different ages. European Journal of Applied Physiology, 70, 518-527.

Hakkinen, K., Kraemer, W.J., Kallinen, M., Lannamo, V., Pastinen, U.M., & Newton, R.U. (1996). Bilateral and unilateral neuromuscular function and muscle cross-sectional area in middle-aged and elderly men and women. Journal of Gerentological Biological Science, 51A, 21-29.

Harmenbert, J., Ceci, R., Barvestad, P., Hjerpe, K., & Nystrom, J. (1991). Comparison of different tests of fencing performance. International Journal of Sports Medicine, 12, 573-576.

Hascelik, Z., Basgoze, O., Turker, K., Narman, S., & Ozker, R. (1989). The effects of physical training on physical fitness tests and auditory and visual reaction times of volleyball players. The Journal of Sports Medicine and Physical Fitness, 29, 234-239.

Hatta, A., Nishihira, Y., Kim, S.R., Kaneda, T., Kida, T., Kamijo, K., Sasahara, M., & Haga, S. (2005). Effects of habitual moderate exercise on response processing and cognitive processing in older adults. Japanese Journal of Physiology, 55, 29-36.

Henatsch, H.D., & Langer, H.H. (1985). Basic neurophysiology of motor skill in sports: A review. International Journal of Sports Medicine, 6, 2-14.

Hertzog, C., Vernon, M.C., & Rypma, B. (1993). Age differences in mental rotation task performance: the influence of speed/accuracy tradeoffs. Journal of Gerontology, 48, 150-156.

Hesselmann, V., Zaro, W., & Wedekind, C. (2001). Age related signal decrease in functional magnetic resonance imaging during motor stimulation in humans. Neuroscience Letters, 308, 141-144.

Hick, W.E. (1952). On the rate of gain of information. Quarterly Journal of Experimental Psychology, 4, 11-26.

Hillman, C., Snook, E., & Jerome, G. (2003). Acute cardiovascular exercise and executive control function. International Journal of Psychophysiology, 48, 307-314.

Hillman, C.H., Weiss, E.P., Hagberg, J.M., & Hatfield, B.D. (2002). The relationship of age and cardiovascular fitness to cognitive and motor processes. Psychophysiology, 39, 303-312.

Hodgkins, J. (1962). Influence of age on the speed of reaction and movement in females. Journal of Gerontology, 17, 385-389.

Howley, E.T., Bassett, D.R.J., & Welch, H.G. (1995). Criteria for maximal oxygen uptake: Review and commentary. Medicine and Science in Sports and Exercise, 27, 1292-1301.

Hubbard, A.W. (1956). Peripheral perception and reaction time. Paper presented at the American Association for Health, Physical Education and Recreation Research Section, Chicago, Ill.

Hyman, R. (1953). Stimulus information as a determinate of reaction time. Journal of Experimental Psychology, 45, 188-196.

Isaacs, L.D., & Pohlman, R.L. (1991). Effects of exercise intensity on an accompanying timing task. Journal of Human Movement Studies, 20, 123-131.

Irvy, R.B. (1986). Force and timing components of the motor program. Journal of Motor Behavior, 18, 449-474.

Ito, M. (1997). Fractionated reaction time as a function of magnitude of force in simple and choice conditions. Perceptual and Motor Skills, 85, 435-444.

Ives, J.C., & Shelley, G.A. (2003). Psychophysics in functional strength and power training: review and implementation framework. The Journal of Strength and Conditioning Research, 17, 177-186.

Izquierdo, M., Aguado, X., Gonzalez, R., Lopez, J.L., & Hakkinen, K. (1999). Maximal and explosive force production capacity and balance performance in men of different ages. European Journal of Applied Physiology, 79, 260-267.

Jackson, A., & Pollock, M. (1985). Practical assessment of bodily composition. Physician Sports Medicine, 13, 76-90.

Jackson, W.C. (1971). Explosive muscular power, reaction time and running speed within and between college athletes and non-athletes. Unpublished Masters Thesis, Eastern Illinois University, Urbana.

Jacobs, E.A., Winter, P.M., Alvis, H.J., & Small, S.M. (1969). Hyperoxygenation effect on cognitive functioning of the aged. New England Journal of Medicine, 281, 754-759.

Jensen, B.E. (1975). Pretask speed training and movement complexity as factors in rotary pursuit skill acquisition. Research Quarterly, 46, 1-11.

Johnson, M., Bebb, R., & Sirrs, S. (2002). Uses of DHEA in aging and other disease states. Aging Research Reviews, 1, 29-41.

Kahn, A., Sane, D., Wannenburg, T., & Sonntag, W. (2002). Growth hormone, insulin-like growth factor-1 and the aging cardiovascular system. Cardiovascular Research, 54, 25-35.

Kalapotharakos, V., Michalopoulos, M., Strimpakos, N., Diamantopoulos, K., & Savvas, T. (2006). Functional and neuromotor performance in older adults: Effect of 12 weeks of aerobic exercise. American Journal of Physical Medicine and Rehabilitation, 85, 61-67.

Kawabe-Himeno, S. (1991). Effects of speed and accuracy of exertion of force on the relationship between force output and fractionated reaction time. Perceptual and Motor Skills, 73, 327-334.

Keller, L.F. (1942). Relation of quickness of bodily movement to success in athletics. Research Quarterly, 13, 146-155.

Kerr, R., & Boucher, J. (1992). Knowledge and motor performance. Perceptual and Motor Skills, 86, 771-786.

Koga, Y., & Morant, G.M. (1923). On the degree of association between reaction times in the use of different senses. Biometrika, 15, 346-372.

Kuhlman, J.S., & Beitel, P.A. (1989). Age/sex/experience: Possible explanations of differences in anticipation of coincidence. Perceptual and Motor Skills, 68, 1283-1289.

Kuhlman, J.S., & Beitel, P.A. (1992). Coincidence anticipation: Possible critical variables. Journal of Sport Behavior, 15, 91-105.

Larsson, L. (1978). Morphology and functional characteristics of the aging skeletal muscle in man. Acta Physiologica Scandinavia, 457, 1-37.

Lexell, J. (1995). Human aging, muscle mass, and fiber type comparison. Journal of Gerontology, 50, 11-16.

Lexell, J., Henriksson-Larsen, K., Winblad, B., & Sjostrom, M. (1983). Distribution of different fiber types in human skeletal muscles: Effects of aging studied in whole muscle cross sections. Muscle Nerve, 6, 588-595.

Lexell, J., Taylor, C.C., & Sjostrom, M. (1988). What is the cause of the aging atrophy? Journal of Neurological Science, 84, 275-294.

Liepert, J., Tegenthoff, M., & Malin, J.P. (1995). Changes of cortical motor area size during immobilization. Electroencephalography and Clinical Neurophysiology, 97, 382-386.

Linde, L.M. (1963). An appraisal of exercise fitness tests. Pediatrics, 32, 656-659.

McFarland, R.A. (1963). Experimental evidence of the relationship between aging and oxygen want: In search of a theory of aging. Ergonomics, 6, 339-366.

McMorris, T., Delves, S., Sproule, J., Lauder, M., & Hale, B. (2005). Effect of incremental exercise on initiation and movement times in a choice response, whole body psychomotor task. British Journal of Sports Medicine, 39, 537-541.

Meeuwsen, H.J., Goode, S.L., & Goggin, N.L. (1997). Effects of aging on coincidence anticipation timing in females. Journal of Aging and Physical Activity, 5, 285-297.

Mokhu, R., Kaur, G., & Sidhu, L.S. (1992). The effect of training on the reaction time of Indian female hockey players. The Journal of Sports Medicine and Physical Fitness, 32, 428-431.

Mori, S., Ohtani, Y., & Imanaka, K. (2002). Reaction times and anticipatory skills of karate athletes. Human Movement Science, 21, 213-230.

Newell, K.M., Carlton, L.G., Carlton, M.J., & Halbert, J.A. (1980). Velocity as a factor in movement timing accuracy. Journal of Motor Behavior, 12, 47-56.

Noble, C.E. (1978). Age, race, and sex in the learning and performance of psychomotor skills. In R.T. Osborne, C.E. Noble, & N. Weyl (Eds.), Human variation: The biopsychology of age, race, and sex. New York: Academic Press.

Oguz, K., Browner, N., Calhoun, V., Wu, C., Kraut, M., & Yousem, D. (2003). Correlation of functional MR imaging activation data with simple reaction times. Radiology, 226, 188-194.

Pascual-Leone, A., Dang, N., Cohen, L.G., Brasil-Neto, J.P., Cammarota, A., & Hallett, M. (1995). Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills. Journal of Neurophysiology, 74, 1037-1045.

Pew, R.W. (1970). Toward a process-orientated theory of human skilled performance. Journal of Motor Behavior, 2, 8-24.

Powell, R. (1983). Reaction time changes following aerobic conditioning. Journal of Human Movement, 9, 145-150.

Rogers, M.A., & Evans, W.J. (1993). Changes in skeletal muscle with aging: Effects of exercise training. In J. Holloszy (Ed.), Exercise and Sports Sciences Review: Vol. 21 (pp. 65-102). Philadelphia: Williams & Wilkins.

Rosenbaum, D.A., Inhoff, A.W., & Gordon, A.M. (1984). Choosing between movement sequences: A hierarchical editor model. Journal of Experimental Psychology: General, 113, 372-393.

Rotella, R.J., & Bunker, L.K. (1978). Field dependence and reaction time in senior tennis players (65 and over). Perceptual and Motor Skills, 46, 585-586.

Sage, G.H., and Hornak, J.E. (1978). Progressive speed practice in learning a continuous motor skill. The Research Quarterly, 49, 190-196.

Schmidt, R.A. (1975a). Motor skills. New York: Harper and Row.

Schmidt, R.A. (1975b). A schema theory of discrete motor skill learning. Psychological Review, 82, 225-260.

Schmidt, R.A. (1982). Motor control and learning. Champaign, IL: Human Kinetics.

Schmidt, R.A., Zelaznik, H.N., & Frank, J.S. (1978). Sources of inaccuracy in rapid movement. In G.E. Stelmach (Ed.), Information processing in motor control and learning. New York: Academic Press.

Schmidt, R.A., Zelaznik, H.N., Hawkins, B., Frank, J.S., & Quinn, J.T. (1979). Motor-output variability: A theory for the accuracy of rapid motor acts. Psychological Review, 86, 415-451.

Sherwood, D.E., & Schmidt, R.A. (1980). The relationship between force and force variability in minimal and near-maximal static and dynamic contractions. Journal of Motor Behavior, 12, 75-89.

Siegel, D. (1994). Response velocity, range of movement and timing accuracy. Perceptual and Motor Skills, 79, 216-218.

Simonen, R.L., Videman, T., Battie, M.C., & Gibbons, L.E. (1998). The effect of lifelong exercise on psychomotor reaction time: A study of 38 pairs of male monozygotic twins. Medicine and Science in Sports and Exercise, 30, 1445-1450.

Smith, K.U., & Greene, D. (1962). Scientific motion study and aging processes in performance. Ergonomics, 5, 155-164.

Smith, P.E. (1968). Investigation of total-body and arm measures of reaction time, movement time, and completion time for twelve, fourteen and seventeen year old athletes and non-participants. Unpublished Masters Thesis in Physical Education, University of Oregon, Eugene.

Southard, D. (1989). Changes in limb striking patterns: effects of speed and accuracy. Research Quarterly for Exercise and Sport, 60, 348-356.

Sparrow, W., Parker, S., Lay, B., & Wengier, M. (2005). Aging effects on the metabolic and cognitive energy cost of interlimb coordination. Journal of Gerontology, 69A, 312-320.

Spieth, W. (1965). Slowness of task performance and cardiovascular diseases. In A. T. Welford & J.E. Birren (Eds.), Behavior, aging and the nervous system (pp.366-400). Springfield, IL: Thomas.

Spirduso, W. (1975). Reaction and movement time as a function of age and physical activity level. Journal of Gerontology, 30, 435-440.

Spirduso, W. (1980). Physical fitness, aging, and psychomotor speed: A review. Journal of Gerontology, 35, 850-865.

Spirduso, W. (1982). Exercises and the aging brain. Research Quarterly for Exercise and Sport, 54, 208-218.

Spirduso, W., & Clifford, P. (1978). Replication of age and physical activity effects on reaction and movement time. Journal of Gerontology, 33, 26-30.

Stein, T., & Wade, C. (2005). Metabolic consequences of muscle disuse atrophy. The Journal of Nutrition, 135, 1824S-1828S.

Steitz, E.S. (1963). The relationship of reaction time, speed, Sargent jump, physical fitness and other variables to success in specific sports. Unpublished Master's Thesis, Springfield College.

Tan, U. (1990a). Testosterone and nonverbal intelligence in right handed men and women. International Journal of Neuroscience, 54, 277-282.

Tan, U. (1990b). Relationship of testosterone and nonverbal intelligence to hand preference and hand skills in right handed young adults. International Journal of Neuroscience, 54, 283-290.

Tan, U., Akgun, A., & Telatar, M. (1993). Relationships among nonverbal intelligence, hand speed and serum testosterone level in left-handed male subjects. International Journal of Neuroscience, 71, 21-28.

Tan, U., & Tan, M. (1998). Curvelinear correlations between total testosterone levels and fluid intelligence in men and women. International Journal of Neuroscience, 95, 77-83.

Taylor, H.L., Wang, Y., Rowell, L., & Blomquist, G. (1963). The standardization and interpretation of submaximal and maximal tests of working capacity. Pediatrics, 32, 703-720.

Uyanik, B.S., Ari, Z., Gumus, B., Yigitoglu, M.R., & Arslan, T. (1997). Beneficial effects of testosterone undecanoate on the lipoprotein profiles in healthy elderly men: A placebo controlled study. Japanese Heart Journal, 38, 73-82.

Uysal, N., Tugyan, K., Kayatekin, B., Acikgoz, O., Bagriyanik, H., Gonenc, S., Ozdemir, D., Aksu, I., Topcu, A., & Semin, I. (2005). The effects of regular aerobic exercise in adolescent period on hippocampal neuron density, apoptosis and spatial memory. Nueuroscience Letters, 383, 241-245.

Wise, P., Dubal, D., Wilson, M., Rau, S., Bottner, M., & Rosewell, K. (2001). Estradiol is a protective factor in adult and aging brain: Understanding of mechanisms derived from in vivo and in vitro studies. Brain Research Reviews, 37, 313-319.

Woods, J.B. (1965). The effect of varied instructional emphasis upon the development of a motor skill. The Research Quarterly, 38, 132-142.

Woodworth, R.S. (1899). The accuracy of voluntary movement. Psychological Review Monograph Supplement, 3, 13.

Wright, C.E., & Meyer, D.E. (1983). Conditions for a linear speed-accuracy trade-off in aimed movements. Quarterly Journal of Experimental Psychology, 35A, 279-296.

Xu, D., Li., J., & Hong, Y. (2006). Effects of long term tai chi practice and jogging exercise on muscle strength and endurance in older people. British Journal of Sports Medicine, 40, 50-54.

Yagi, Y., Coburn, K.L., Estes, K.M., & Arruda, J.E. (1999). Effects of aerobic exercise and gender on visual and auditory P300, reaction time and accuracy. European Journal of Applied Physiology, 80, 402-408.

Vandervoort, A. (2001). Aging of the human neuromuscular system. Muscle & Nerve, 25, 17-25.

Yiou, E., & Do, M. (2000). In fencing, does intensive practice equally improve the speed performance of touché when it is performed alone and in combination with the lunge? International Journal of Sports Medicine, 21, 1-5.

Yiou, E., & Do, M. (2001). In a complex sequential movement, what component of the motor program is improved with intensive practice, sequence timing or ensemble motor learning? Experimental Brain Research, 137, 197-204.

Youngen, L. (1959). A comparison of reaction and movement times of women athletes and non-athletes. Research Quarterly, 30, 349-355.

APPENDIX A

INFORMED CONSENT FORM

(An evaluation of psychomotor control in fit and unfit young adult males)
Joshua McCaig

1. Purpose of the Study

The aim of this study is to compare psychomotor control in fit and unfit young adult males.

2. Benefits of the Study

The benefit of the study to you is that you will receive a free fitness evaluation that includes aerobic, strength, blood pressure and body fat measurements. It also allows you to gain knowledge about experimental research through direct participation.

The benefit to society includes a better understanding of the areas that are affected by exercise. It will allow for an increase in the understanding of psychomotor control and serve as an exploratory study that will raise other questions for future research.

3. What You Will Be Asked to Do

You will be asked to devote less than three hours of time over the course of three weeks. There will be an initial meeting that will provide the information to determine who qualifies to participate in the experiment. If you are selected you will come in for one session of preliminary fitness evaluation. This will include aerobic fitness through exercise on a treadmill and strength assessment through bench press and hand grip strength. Other measurements that will be taken include body fat measurements, height and weight. All this will be done in under forty minutes during the first week. You will then need to show up for the experimental testing two days during the next two weeks. There is to be one day in between testing days. The testing will take approximately fifteen minutes for each day. You will be standing while holding a handle attached to a lever with the right hand. The lever will swing horizontally. There will be four stimulus lights. Each light will require you to move the lever to a certain position as quickly and accurately as possible. This will be performed for two sets of forty trials on each testing day.

4. Risks

As with any exercise, there exists the possibility of health risks if caution is not observed. VO2 max testing can result in nausea, light-headedness, passing out and vomiting. There is a chance of stroke or death in high risk people but this will be assessed at the initial screening with a PAR-Q evaluation. You will not be permitted to participate in the study if you are assessed to be at high risk. It also may result in muscle and joint soreness for the following days. Trained specialists and technicians will be present to administer the tests in order to ensure your safety. The strength tests as well as the experimental trials may bring some muscle soreness on the following days. There also exists the potential to pull a muscle. Again, trained technicians will be present to ensure correct form in the movements and to maintain your safety. The potential risks would be short term and there are no expected long-term effects of this study.

5. If You Would Like More Information about the Study

Feel free to contact either Joshua McCaig (256-8245) or Dr. Jeff Ives (274-1751) with further questions at any time.

6. Withdrawal from the Study

Participation in this study is voluntary and you may withdraw at any time if you so choose.

7. Confidentiality

Information gathered during this study will be maintained in complete confidentiality. Only Mr. McCaig and Dr. Ives will have access to the information. All reporting to outside parties will be done in group form. You and your name will never be associated with this information in any future disclosures.

Please sign and date below.

I have read the above consent form and understand its contents. I acknowledge that I am at least 18 years of age or older and agree to participate in this study.

________________________________ ________________

Signature Date

APPENDIX B

PHYSICAL ACTIVITY QUESTIONNAIRE

In this section we would like to ask you about your current physical activity and exercise habits that you perform regularly, at least once a week. Please answer as accurately as possible. Circle you answer or supply a specific number when asked.

EXERCISE/PHYSICAL ACTIVITY

1. For the last three months, which of the following moderate or vigorous activities have you performed regularly? (Please circle YES for all that apply and NO if you do not perform the activity; provide an estimate of the amount of activity for all marked YES. Be as complete as possible.)

Walking (i.e., to class)
NO YES How many sessions per week? _______
How many miles (or fractions thereof) per session? _______
Average duration per session? _________(minutes)

What is your usual pace of walking? (Please circle one)

Casual or strolling, <2mph
Average or Normal, 2-3mph
Fairly Brisk, 3-4mph
Brisk or Striding, >4mph

Stair Climbing
NO YES How many flights of stairs do you climb UP each day? _________
(1 flight = 10 steps)

Jogging or Running
NO YES How many sessions per week? _______
How many miles (or fractions thereof) per session? _______
Average duration per session? _________(minutes)

Treadmill
NO YES How many sessions per week? _______
Average duration per session? _________(minutes)
Speed? ________(mph) Grade? _______%

Bicycling
NO YES How many sessions per week? _______
How many miles (or fractions thereof) per session? _______
Average duration per session? _________(minutes)

Swimming Laps

NO YES How many sessions per week? _______

How many miles (or fractions thereof) per session? _______

(880 yards = .5 miles)

Average duration per session? _________(minutes)

Aerobic Dance/Calisthenics/Floor Exercise

NO YES How many sessions per week? _______

Average duration per session? _________(minutes)

Moderate Sports

(e.g., Leisure volleyball, golf (not riding), social dancing, doubles tennis)

NO YES How many sessions per week? _______

Average duration per session? _________(minutes)

Vigorous Racquet Sports

(e.g., racquetball, singes tennis)

NO YES How many sessions per week? _______

Average duration per session? _________(minutes)

Other Vigorous Sports or Exercise Involving Running

(e.g., basketball, soccer)

NO YES Please specify? ___________________________

How many sessions per week? _______

Average duration per session? _________(minutes)

Other Activities

NO YES Please specify? ____________________

How many sessions per week? _______

Average duration per session? _________(minutes)

Please specify? ____________________

How many sessions per week? _______

Average duration per session? _________(minutes)

Weight Training

(Machines, free weights)

NO YES How many sessions per week? _______

Average duration per session? _________(minutes)

Household Activities

(Sweeping, vacuuming, washing clothes, scrubbing floors)

NO YES How many hours per week? _______

Lawn Work and Gardening
NO YES How many hours per week? _______

2. How many times a week do you engage in vigorous physical activity long enough to work up a sweat? ________(times per week)

3. For what period of time have you been engaging in the vigorous physical activity?
Years __________ Months ___________

4. List all organized sports that you have participated in and when (High School or College)

Sport	When
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________

5. If you have a job or any other duties that require physical activity, please list them and the frequency at which they are performed below.

Activity	Frequency
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________

I state that I have read and understood the questions in this questionnaire and have answered them honestly.

SIGNATURE: ________________________ DATE: ______________

(Adapted from the Aerobics Center Longitudinal Study Physical Activity Questionnaire, Dr. Steven N. Blaire, 1988)

APPENDIX C

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

PAR-Q & YOU
(A Questionnaire for People Aged 15-69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not physically active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you have pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in physical activity?
☐	☐	6.	Is you doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of any other reason why you should not do physical activity?

If you answered:

YES, to one or more questions:

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want, as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advise.
- Find out which community programs are safe and helpful for you.

NO, to all questions:

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active, begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal, this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

Delay becoming more active:

- If you are not feeling well because of a temporary illness such as a cold or fever, wait until you feel better; or
- If you are or may be pregnant, talk to your doctor before you start becoming more active.

NOTE: If your health changes so that you answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name (Print): ______________________________

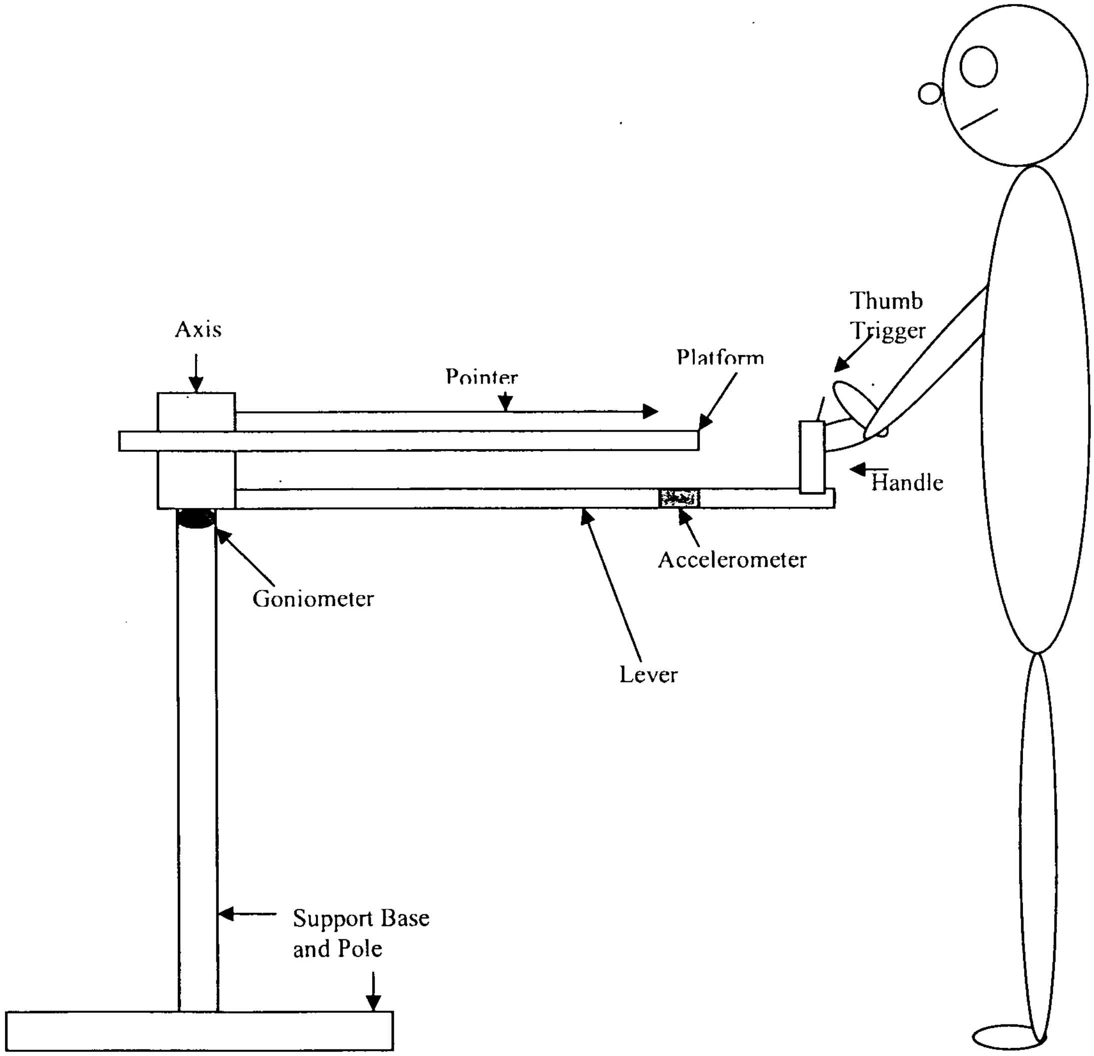
Signature: ________________________________ Date: _____________

Witness: __________________________________ Date: _____________

APPENDIX D

SCHEMATIC OF THE TESTING APPARATUS

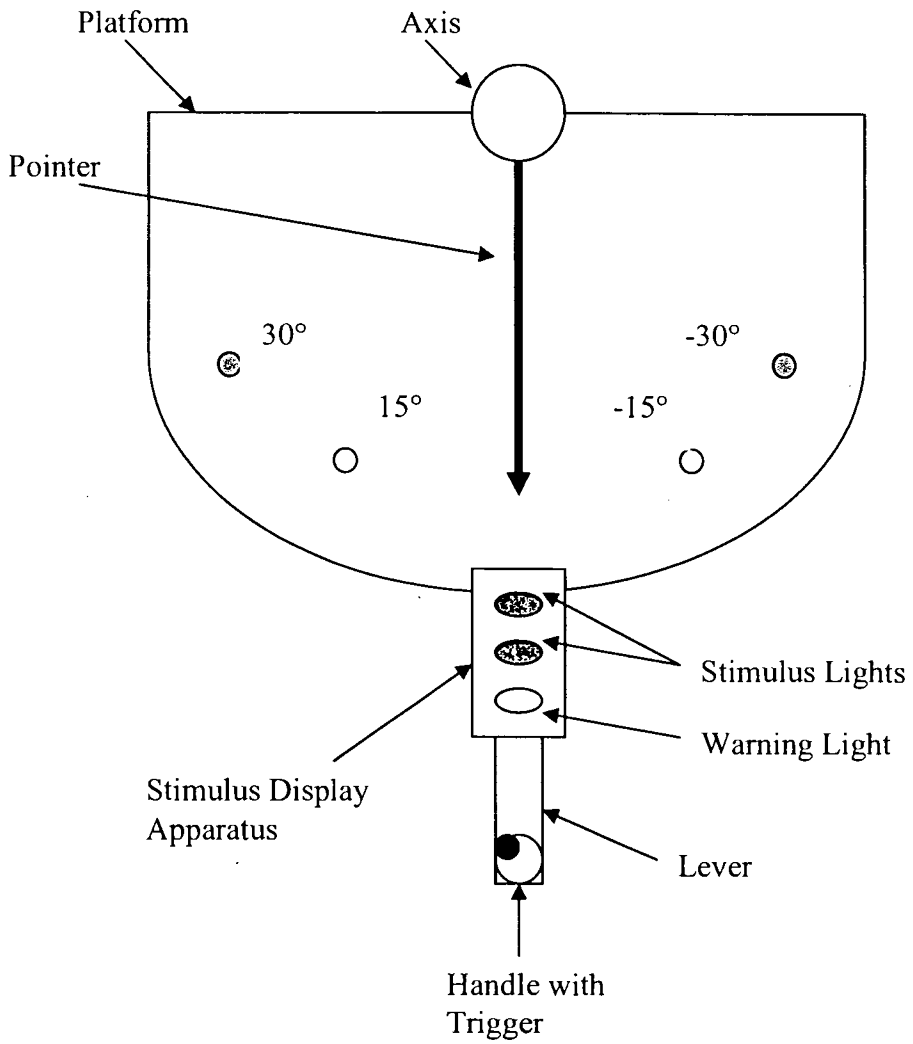
SIDE VIEW



APPENDIX D (CONTINUED)

SCHEMATIC OF THE TESTING APPARATUS

TOP VIEW



APPENDIX E

SAMPLE SCHEMATIC OF DATA COLLECTION COMPUTER PROGRAM