RELATIONSHIP BETWEEN STRENGTH, PHYSICAL ACTIVITY, GENDER, AND FRACTIONED REACTION TIME

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ABSTRACT

STEWART YOUNG: Relationship Between Strength, Physical Activity, Gender, and Fractioned Reaction Time
(Under the direction of Bonita L. Marks, Ph.D.)

This study explored the relationship between strength, physical activity, and fractioned reaction time. This study also examined the influence of gender on these relationships. The variables examined included peak strength, relative strength, pre-motor time, electromechanical delay, and total reaction time. A sample of 12 males and 12 females, 18-29 years old, performed five trials of a maximal voluntary isometric contraction in the hamstring muscle group to determine strength and fractioned reaction time. A significant inverse relationship between peak strength and total reaction time was observed ($r = -0.455$, $p = 0.026$). Additionally, a significant inverse relationship was observed between relative strength and total reaction time ($r = -0.448$, $p = 0.028$). No other relationships examined were significant. Gender significantly influenced the relationships between peak and relative strength and TRT by rendering the correlations non-significant but no other gender influence was observed. These findings suggest that stronger individuals will display shorter reaction times.

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LIST OF ABBREVIATIONS

ANOVA = Analysis of Variance

EMD = Electromechanical Delay

EMG = Electromyography

ICC = Intraclass Correlation Coefficient

Z_{obs} = Observed Value of z

PMT = Pre-motor Time

SEM = Standard Error of the Mean

TRT = Total Reaction Time

CHAPTER ONE

Introduction

Reaction time is an important factor in the success of almost every sport or athletic event. At the elite sport level, milliseconds can mean the difference between winning and second place. For instance, at the 2008 Beijing Summer Olympic Games, the difference between the first and second place finishers in the men's 100 meter dash was 0.2 seconds and the difference between second and third was 0.02 seconds (International Association of Athletics Federation). A fast reaction time can be the deciding factor that helps an athlete achieve success.

Reaction time is the time delay between when a stimulus is presented and when muscular force is produced. Further, reaction time is comprised of two components, or fractions (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981). The first fraction is an interval of time between when a stimulus is presented and a change in electrical activity in the muscle is observed (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981). The first fraction is referred to as pre-motor time (PMT). The second fraction is the time delay between the change in electrical activity in the muscle and the onset of force production (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Panton et al. 1990). This fraction is called electromechanical delay (EMD). Both fractions combine to make total reaction time (TRT). Previous research shows that a substantial portion of time between the onset of EMG activity and force production (EMD) can be attributed to several mechanisms including the transmission of the nervous signal over the muscle membrane, the excitation contraction coupling process, and the stretching of the series elastic component (Blackburn et al. 2009; Cavanagh and Komi 1979; Grosset et al. 2009; Sandow 1965; Viitasalo and Komi 1981). However, it has been shown that the time taken to stretch the elastic components is the main contributor to EMD in vivo (Cavanagh and Komi 1979; Grosset et al. 2009). When contraction begins, tension must first be created in the muscle tissue and tendons before force can be transferred to a joint. It is thought that greater strength will result in greater ability to take up the "slack" and produce force more rapidly. The relationship between strength and EMD has not been examined in this capacity in a healthy population.

Many studies have investigated the impact of gender, age, fiber composition, injury risk, force production, time of day, anxiety, and strength training programs on fractioned reaction time (Behm et al. 2004; Bell and Jacobs 1986; Blackburn et al. 2009; Clarkson 1978; Frewer and Hindmarch 1988; Linford et al. 2006; Liu-Ambrose et al. 2004; Mero and Komi 1990; Panton et al. 1990; Rooks et al. 1997; Sale et al. 1983; Viitasalso and Komi 1978; Viitasalo and Komi 1981). Of those, several focused on the effect of a strength training program on strength and reaction time in elderly populations (Liu-Ambrose et al. 2004; Panton et al. 1990; Rooks et al. 1997).

One previous study (Viitasalo and Komi 1981) examined the relationship between strength and reaction time in 29 males (22.2 ± 2.25 yrs). However, the focus of this study was to examine the impact of fiber type distribution on reaction time and not strength per se. Subjects completed a maximal voluntary isometric knee extension in response to auditory or visual stimuli. Fractioned reaction time and strength were measured from the vastus lateralis muscle and a significant inverse relationship was reported between EMD and maximal force but no significant relationship was seen between TRT and strength. EMD also demonstrated a significant positive relationship with percentage of slow twitch fibers. These relationships were attributed to an increased percentage of fast twitch fibers. As interesting as these findings are, the study's results and conclusions must be examined with caution. Several studies (Campos et al. 2002; Wakahara et al. 2010; Harber et al.

2004) have demonstrated that training can increase the percentage of fast twitch fibers as well as cross sectional area of the muscle. Cross sectional area has been significantly correlated with maximal force production in both males and females (Maughan et al. 1983). The results from Viitasalo and Komi (1981) may not be due to a greater percentage of fast twitch fibers but rather greater strength, as demonstrated by the significant inverse correlation between EMD and maximal force. The study design also failed to control for differences in strength and reaction time due to body mass differences or physical activity/training status. Large differences in strength due to body mass become normalized when strength is expressed in relative units. By including relative and absolute strength in the present study, we were able to determine the impact of body mass on the relationship between strength and fractioned reaction time. Additionally, auditory and visual stimuli were used to initiate voluntary muscular contractions which could have influenced the results. Brebner and Welford (1980) demonstrated that auditory stimuli result in a faster reaction time than visual stimuli which is why the results from Viitasalo and Komi (1981) must be viewed cautiously.

Three previous studies have examined fractioned reaction time with a focus on gender differences (Bell and Jacobs 1986; Blackburn et al. 2009; Morris and Beaudet 1980). In the first study (Bell and Jacobs 1986), subjects ranged in age from 19-46 and varied in physical training history from sedentary to regular participants in strength training. Their task was to perform maximal voluntary isometric contractions of the biceps brachii while holding onto a bar with a force transducer attached. Fractioned reaction time and strength were measured from the biceps brachii and although TRT was similar across all groups, there were distinct differences in strength with males having greater absolute strength and shorter EMD (Bell and Jacobs 1986). The authors concluded that the differences in reaction time displayed between males and females may not have been due to gender, but rather may have been due to differences in strength (Bell and Jacobs 1986). This was attributed to potential structural differences in the fibers between the genders, with males perhaps being more resistant to stretching and females not able to recruit sufficient motor units (Bell and Jacobs 1986). However, it has been shown that muscular stiffness has no effect on EMD (Blackburn et al. 2009). Therefore, the differences in EMD seen by Bell and Jacobs (1986) might have been due to a physiological adaptation that stronger individuals possess. Stronger individuals are able to recruit more motor units and have more cross bridge interaction between actin and myosin. Thus, a stronger muscle has a greater rate of force production, causing the time delay between electrical and mechanical onsets (EMD) to be reduced.

Again, the results and conclusions from this study need to be viewed cautiously. The study design did not control for strength and reaction time differences due to the wide age range, body mass differences, or physical activity/training status within or between genders. All of these variables have been shown to influence both strength and reaction time and could have potentially confounded the results (Botwinick and Thompson 1968; Panton et al. 1990; Rooks et al. 1997; Spirduso 1975; Spirduso and Clifford 1978). The precise cause for the differences is unclear. Furthermore, measuring upper extremity reaction time and strength has limited practical utility because it cannot be applied directly to performance in the majority of athletic events.

Blackburn et al. (2009) examined EMD in 20 males and 19 females using force production during maximal isometric contractions in the hamstrings and found no difference in EMD between males and females. The average EMD for males was 125.43 ms compared to 127.49 ms for females.

The third study investigating gender and reaction time (Morris and Beaudet 1980) examined 22 subjects (11 males, 11 females [21.1 ± 1.8 yrs]) who performed maximal voluntary isometric contractions with five separate muscle groups. Force was not reported but EMD was shown to be similar between genders in all muscle groups. These findings support those of Blackburn et al. (2009) and are contrary to those of Bell and Jacobs (1986) mentioned earlier and present a contradiction in the literature. Further investigation is needed to clarify relationships between strength, gender, and fractioned reaction time.

Statement of the Problem

Lower extremity reaction time has wide applicability for performance in almost all sports. An extensive literature review conducted on PubMed (1970-2010) revealed no published studies examining both the fractions of reaction time as well as strength in the lower extremity (hamstrings) in both genders. Therefore, the primary purpose of the present study was to examine the relationship between strength, physical activity, and fractioned reaction time (PMT, EMD, and TRT) in the hamstrings. A secondary purpose was to explore the influence of gender on these relationships.

Aims and Hypotheses

The first aim of this study was to examine relationships between strength and fractioned reaction time variables. A second aim was to determine the relationship between physical activity and fractioned reaction time variables. The third aim of this study was to determine the influence of gender upon the fractioned reaction time variables. The research hypotheses are listed below:

Hypothesis 1. There will be a relationship between strength, physical activity, and electromechanical delay (EMD).

Hypothesis 1a. Gender will not influence the relationship between strength, physical activity, and EMD.

Hypothesis 2. There will be no relationship between strength, physical activity, and pre-motor time (PMT).

Hypothesis 2a. Gender will not influence the relationship between strength, physical activity, and PMT.

Hypothesis 3. There will be a relationship between strength, physical activity and total reaction time (TRT).

Hypothesis 3a. Gender will not influence the relationship between strength, physical activity, and TRT.

Definitions

Total reaction time (TRT). The total time delay between when a stimulus is presented and when force is produced by the muscle (includes PMT and EMD) (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981).

Fractioned reaction time. Reaction time that is broken down into two components: pre-motor time (PMT) and electromechanical delay (EMD) (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981).

Pre-motor time (PMT). The time delay between when a stimulus is presented and when electrical activity in the muscle is detected (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981).

Electromechanical delay (EMD). The time delay between when electrical activity in the muscle is detected and when force is produced by the muscle (Bell and Jacobs 1986; Blackburn et al. 2009; Cavanagh and Komi 1979; Mero and Komi 1990; Viitasalo and Komi 1981).

Strength. The amount of force a muscle or group of muscles can produce. Strength will be measured through maximal voluntary isometric contractions (Bell and Jacobs 1986; Blackburn et al. 2009).

Peak strength. The maximal amount of force produced during a maximal voluntary isometric contraction (N).

Relative strength. The amount of force produced per unit body mass during a maximal voluntary isometric contraction (N/kg).

Delimitations

This study was delimited to healthy subjects, aged 18-29, without known neurological disorders and no lower extremity injuries for 6 months prior to participation. Pregnant volunteers were restricted from participation due to known joint laxity issues that occur during pregnancy (Calguneri et al. 1982; Schauberger et al. 1996). Therefore, generalizability is limited to younger adults. This study was also delimited to the measurement of isometric exercises and reaction time using only the lower extremity (hamstrings) since a greater number of sports involve lower extremity muscular contractions. Therefore, these results may not be generalizable to sports primarily involved with upper body muscular contractions, nor to other types of muscular contractions (i.e. isotonic or isokinetic).

Subjects abstained from caffeine ingestion prior to their testing session. Previous research is inconclusive on this topic. However, several studies indicate an increase in reaction time with caffeine doses as little as 75 mg (Clubley et al. 1979; Lieberman et al. 1987). Therefore, to prevent unintentional confounding of the results due to caffeine ingestion, subjects refrained from ingesting caffeine for 24 hours prior to their testing session. This was verified via self-report on the day of testing.

Limitations

The use of self-reporting for caffeine abstinence was an anticipated limitation as the investigators needed to rely on the subjects reporting honestly and accurately their caffeine use for the previous 24 hours.

Assumptions

1. Subjects recalled information regarding physical, activity, medical conditions, and caffeine ingestion accurately.
2. The researcher appropriately reviewed the questionnaire with the subjects.

Significance of the Study

The significance of this study is that it could provide insight into the relationship between strength and fractioned reaction time. This could provide new evidence for coaches and trainers to help improve their athlete's reactive capabilities without spending valuable training time on specialized reaction drills. It can also provide information for talent evaluation by identifying which athletes possess both high levels of strength and high reactive capabilities.

CHAPTER TWO

Review of Literature

Reaction time is vital for performance in almost every sporting event. For example, in the sport of baseball, a pitcher can throw the ball at speeds exceeding 90 miles per hour. A ball traveling at 90 miles per hour will travel the distance from the pitching mound to home plate in 0.45 seconds. Elite baseball players are able to react to the pitch and begin their swing all in less than half a second. Because reaction time is such an important part of success in elite athletic competition, it is often the case that winning and losing are separated by only fractions of a second.

Reaction time can be defined in a number of ways. The starting point for measurement is generally accepted as the presentation of a stimulus. However, the type of stimulus used in previous research varies between a visual and auditory queue. The type of queue has been shown to affect total reaction time (TRT) with auditory stimuli producing a shorter reaction time than visual stimuli (Brebner and Welford 1980; Winter and Brookes 1991). The difference in reaction time can be attributed to variances in visual versus auditory processing. It takes longer to detect changes in visual intensity than it does to respond to a sound (Brebner and Welford 1980). Table 1 demonstrates the difference in TRT in previous studies that have used auditory stimuli compared to those that have used visual stimuli.

Table 1

Comparison of previous studies examining total reaction time (TRT)

Study	*N*	*Stimulus*	*TRT (ms)*
Weiss (1965)	14	Auditory	173.9
Viitasalo and Komi (1981)	29	Auditory	161.4
Winter and Brookes (1991)	22	Auditory	169.9
Schmidt and Stull (1970)	30	Visual	231.8
Kroll (1974)	11	Visual	246.0
Bell and Jacobs (1986)	86	Visual	194.3

Note. Adapted from Winter and Brookes (1991).

This study will measure reaction time in response to a visual stimulus because it is more applicable to the conditions seen in the majority of athletic events.

The end point for reaction time measurement varies based on the researcher and equipment used. Some studies examining reaction time have used the end point as movement of an extremity (Behm et al. 2004; Clarkson 1978; Clubley et al. 1979; Frewer and Hindmarch 1988; Liu-Ambrose et al. 2004; Panton et al. 1990; Rooks et al. 1997; Winter and Brookes 1991). Studies that measure reaction time with movement often have a subject press a button or remove their finger from a key in response to a stimulus. The purpose of these studies is to examine the functional capacity of an individual, and they often times involve elderly subjects (Clarkson 1978; Liu-Ambrose et al. 2004; Panton et al. 1990; Rooks et al. 1997). The end point of reaction time can also be measured as the onset of force production (Blackburn et al. 2009; Bell and Jacobs 1986; Linford et al. 2006; Mero and Komi 1990; Viitasalo and Komi 1981; Winter and Brookes 1991). These studies often investigate the neuromuscular contributions to reaction time and involve electromyography and load cell equipment. The advantage of measuring reaction time in this capacity is that it allows the investigator to divide reaction time into components and examine the neurological and musculoskeletal events that cause a time delay while at the same time measuring isometric strength in the same muscle group. For these reasons, the present study measured reaction time with electromyography (EMG) and load cell equipment.

Components of Fractioned Reaction Time

Fractioned reaction time is the term given to reaction time that is measured and then divided into two or more components (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981). Previous studies divided reaction time into two fractions: pre-motor time and electromechanical delay. These two fractions combine to make total reaction time (TRT) which is the time delay between the presentation of a stimulus and the onset of force production (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981).

Pre-motor time (PMT) is the time delay between when the stimulus is presented and when electrical activity in the muscle is observed (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981). Pre-motor time is attributed to the time delay caused by the transmission of a nervous impulse from the brain to the skeletal muscle to contract.

Electromechanical delay (EMD) is the time delay between when electrical activity begins in the muscle and when force is produced (Bell and Jacobs 1986; Blackburn et al. 2009; Mero and Komi 1990; Viitasalo and Komi 1981). Electromechanical delay is thought to be due to several factors: the transmission of the nervous signal over the muscle membrane, the excitation contraction coupling process, and the stretching of the series elastic component (Blackburn et al. 2009; Cavanagh and Komi 1979; Grosset et al. 2009; Sandow 1965; Viitasalo and Komi 1981).

The excitation contraction coupling process and the transmission of the neural signal over the muscle membrane comprise some of the time delay observed as EMD. Once an action potential reaches the axon terminal, the neurotransmitter acetylcholine is released into the neuromuscular cleft. Acetylcholine then binds to nicotinic receptors and initiates the opening of voltage gated sodium channels which causes an action potential to travel along the sarcolemma. The action potential then spreads from the surface into the muscle fiber where it reaches the transverse tubules and initiates calcium release from the sarcoplasmic reticulum. Calcium then diffuses into the sarcoplasm and binds to troponin, causing a change in the structure of troponin. This shape change causes tropomyosin to shift on the actin filament and expose binding sites for myosin cross bridges (Fox 2002). These events contribute to the delay observed as EMD.

Once myosin cross bridges attach to actin filaments and muscular contraction begins, tension must be created in the series elastic component before force can be produced. The shortening of the sarcomere caused by contraction will first create tension in the muscle tendon, which is the main structure in the series elastic component. Once tension is created in the tendon, movement and force can be produced at the joint. Studies have shown that in vivo, the main contributor to EMD is the stretching of the series elastic component (Cavanagh and Komi 1979; Grosset et al. 2009). When contraction begins, tension must first be created in the muscle tissue and tendons before force can be produced at a joint. The present study examined reaction time using similar methods to Blackburn et al. (2009). By measuring fractioned reaction time, the present study examined the relationships between gender and strength on TRT, PMT, and EMD.

Strength and Reaction Time

Previous literature has examined reaction time and included strength as a variable (Bell and Jacobs 1986; Morris and Beaudet 1980; Viitasalo and Komi 1981). However, the purpose of these studies was to examine the effects of gender (Bell and Jacobs 1986; Morris and Beaudet 1980) or the effects of fiber type (Viitasalo and Komi 1981) on reaction time and not strength per se.

Viitasalo and Komi (1981) examined the relationship between EMD and percentage of fast and slow twitch fiber distribution. Muscle biopsies were extracted from the vastus lateralis muscle and reaction time was measured during isometric knee extension in response to auditory and visual stimuli. A significant inverse relationship was found between EMD and max force production (r = -0.62). A significant relationship was also shown between EMD and percentage of slow twitch fibers (r = 0.58). The authors conclude that fiber type is the main contributor to EMD. However, these findings must be viewed with respect to the study design. Previous studies have proven that fast twitch fibers are more susceptible to hypertrophy than slow twitch fibers (Campos et al. 2002; Harber et al. 2004; Wakahara et al. 2010). It has also been proven that cross sectional area is significantly correlated with maximal isometric force production in both males and females (Maughan et al. 1983). In this study, the relationship between strength and EMD was stronger than the relationship between fiber type and EMD. This indicates that strength may be the driving factor behind this relationship and not fiber type. Additionally, the maximal force values used were in absolute units (N) and did not account for strength differences in subjects of different sizes. In light of these findings, EMD might be more closely related to relative strength. The present study explored this by examining the relationship between the components of fractioned reaction time and both absolute and relative strength.

Physical Activity and Reaction Time

Like many topics related to reaction time, the literature examining physical activity status and reaction time is inconclusive. Many previous studies that have examined physical activity status and reaction time have done so in an elderly population to determine if activity impacts the age-related slowing of reaction time (Botwinick and Thompson 1968; Panton et al. 1990; Rooks et al. 1997; Spirduso 1975; Spirduso and Clifford 1978).

Rooks et al. (1997) examined the effects of a ten month training program on simple reaction time. Subjects were between the ages of 65-95 and were divided into one of three groups: walking, resistance training, or control (no exercise). Exercises were performed three times per week for a ten week training period and simple reaction time decreased for the exercise groups but not the control group. No difference in reaction time was demonstrated between the walking and resistance training groups. The authors concluded that exercise improves reaction time in the elderly.

Spirduso (1975) examined the effect of physical activity on reaction time in 30 elderly (age 50-70) and 30 young (age 20-30) individuals. Four groups were formed based on age and activity level: old active, young active, old inactive, and young inactive. Old active individuals participated in squash, racquetball, or handball at least three times per week for the previous 30 years while young active individuals participated in squash, racquetball, or handball at least three times per week for two to three years. Inactive individuals did not participate in any activity on a regular basis. Both simple and choice reaction time was measured using a computer program that had subjects remove their finger from a key to depress one key (simple) or one of several keys (choice). Active individuals were found to have a significantly faster choice reaction time in both young and old groups. The author concludes that physical activity provides circulation to the central nervous system that enhances neuronal longevity and efficiency (Spirduso 1975).

Spirduso and Clifford (1978) performed a follow up of Spirduso's original study in 1975 and examined reaction time in elderly and young subjects. Subjects were either young (age 20-30) or old (age 60-70) men and participated in racquet sports or ran at least four times per week, or were inactive. Subjects were divided into six groups: old/young racquet sports, old/young runner, and old/young inactive. Reaction time was measured using the same methods as Spirduso (1975) and the same results were replicated. Active individuals were found to have significantly shorter reaction times compared to inactive individuals their same age. In addition, no difference was demonstrated between the type of activity performed (racquet sports vs. running). An interesting note to the results of this study is that older, active men displayed faster reaction times than young, inactive men, indicating the importance of physical activity in maintaining central nervous system function.

Panton et al. (1990) also examined the effect of a physical activity program on reaction time in 49 healthy, untrained men and women age 70-79. Subjects were divided into one of three groups: control (no exercise), resistance training, or aerobic training and tested on simple reaction time before and after a 26 week training period. The authors found no difference in reaction time between any groups before or after training. The findings are in conflict with Rooks et al. (1997) who found that a training program improved reaction time. The authors indicated in their discussion that the length of the training program might not have been sufficient to elicit a significant improvement in reaction time.

Botwinick and Thompson (1968) also examined reaction time in young active versus young inactive subjects. In order to be included in the active group, subjects must have participated in activity least four days per week. The results show no difference in simple and choice reaction times in the young active group compared to the young inactive group.

The previously mentioned studies have presented conflicting opinions on the effect of physical activity on reaction time. In addition to differing conclusions, previous research has often focused on the elderly with a lack of information on young, healthy populations. Finally, no previous research has examined the impact of physical activity on reaction time in the hamstring muscle group. In order to provide more information on the impact of physical activity and reaction time, the present study examined the relationship between physical activity and reaction time.

Gender and Reaction Time

Previous studies have examined some or all components of fractioned reaction time in both genders (Bell and Jacobs 1986; Blackburn et al. 2009; Morris and Beaudet 1980). Bell and Jacobs (1986) examined 86 males and females age 19-46 who varied in activity level from sedentary to regular participants in strength training. Subjects maximally contracted the biceps brachii in response to a light stimulus. A force transducer was attached to the bar that the subjects held and strength was measured as the peak force produced (N). Male subjects had significantly higher strength scores as well as faster EMD when compared to females. The authors conclude that the gender difference in EMD may be due to structural differences between males and females in the muscle with males being more resistant to stretching and females being less able to recruit motor units (Bell and Jacobs 1986). The results of this study must be questioned because the authors failed to control for strength and reaction time differences due to the wide age range, body mass differences, or physical activity/training status within or between genders. These factors are likely to have confounded the results. By controlling for age, gender, and activity level, the present study offers a more accurate picture of the influence of strength and gender differences on fractioned reaction time.

Blackburn et al. (2009) examined EMD in 20 males and 19 females using the same methods as the present study and found no difference in EMD between males and females. In addition to measuring EMD, Blackburn et al. (2009) also measured musculotendinous stiffness in the hamstring. With subjects positioned prone on a padded table just as in the EMD measurements, a load equal to ten percent of the subject's body weight was attached to the ankle and an accelerometer was secured to a rigid splint placed on the foot. The subjects maintained 30° of knee flexion via isometric contraction and the investigator applied a brief downward manual perturbation at the calcaneous. Stiffness was calculated using the acceleration data and the mass of the shank and foot segment. The results showed that males have significantly greater hamstring stiffness compared to females. These findings seem to contradict the theory of Bell and Jacobs (1986) that males have a shorter EMD because they are resistant to stretching. Blackburn et al (2009) found males to be stiffer than females but there was no significant difference in EMD.

Morris and Beaudet (1980) also examined the effect of gender on EMD. Subjects were tested for EMD on five different muscle groups corresponding to finger, wrist, and elbow flexion, knee extension, and ankle dorsiflexion. Subjects performed a maximal voluntary isometric contraction of each muscle group while EMD was measured. The results revealed no difference in EMD between genders. This finding is in agreement with Blackburn et al. (2009) and in contrast to that of Bell and Jacobs who found a difference in EMD between genders. These conflicting findings could be due to the fact that Morris and Beaudet (1980) did not account for force production differences across genders. For this reason, the present study examined the relationship between fractioned reaction time and strength while accounting for gender. The findings of the present study help to fill a void and clarify the existing literature on the influence of gender on reaction time.

Aside from the studies previously mentioned (Bell and Jacobs 1986; Blackburn et al. 2009; Morris and Beaudet 1980) the remaining literature examining fractioned reaction time involves only male subjects. With few publications examining reaction time and strength in both genders, knowledge on this topic is very limited. In addition, the studies that have included males and females are not in agreement (Bell and Jacobs 1986; Blackburn et al. 2009; Morris and Beaudet 1980). Therefore, the literature on this topic is inconclusive and further examination is needed. Female subjects were included in the present study to examine the contribution of gender to the relationship between strength and fractioned reaction time.

Strength Measurement

In the present study, peak strength (N) was defined as the single peak isometric force produced during five trials. In addition, relative strength was defined as the force produced per unit body mass. Relative strength (N/kg) was calculated by dividing peak force production (N) by the subject's body mass (kg).

Peak isometric force has proven to be an accurate measure of maximal strength. Peak quadriceps isometric force has been strongly correlated ($r = 0.97$) with one repetition maximum back squat in males (age 22 ± 1 years) (McGuigan et al. 2010). Requena et al. (2009) also demonstrated that peak isometric knee extension force significantly correlated with one repetition maximum back squat. Since one repetition maximum is considered the "gold standard" for strength measurement, it can be accepted that peak isometric force is an accurate representation of strength. Therefore, strength was measured in this study as the peak isometric force produced during a maximal voluntary isometric contraction. In addition, because peak strength can be misleading in gender comparisons, relative strength (i.e. strength controlled for body mass) was also evaluated.

Electromyography

Surface electromyography (EMG) is commonly used to examine the timing and magnitude of muscle activity (Fauth et al. 2010). Surface EMG has been examined for reliability in several previous studies (Fauth et al. 2010; Kellis and Katis 2008; Larsson et al. 2003; Viitasalo and Komi 1975). Previous literature has agreed that surface EMG is a reliable measure of muscle activation.

Larsson et al. (2003) examined the reliability of surface EMG in 20 subjects (10 males, 10 females) during repeated maximum concentric knee extensions. Surface EMG readings were conducted on the vastus lateralis, vastus medialis, and rectus femoris while subjects performed 100 contractions on two separate occasions, separated by seven to eight days. EMG readings were reliable with intraclass correlation coefficient (ICC) values ranging from 0.82 - 0.88. Surface EMG was concluded to be a reliable measure of muscle activity. In a similar study, Viitasalo and Komi (1975) examined the reliability and constancy of EMG signal characteristics during submaximal and maximal contractions of the rectus femoris muscle. Six pairs of monozygous twins (14 ± 0.9) were examined on two separate occasions with one day in between sessions. Subjects performed three maximal isometric knee extensions with three minutes rest followed by four contractions at 20%, 40%, 60%, and 80% of maximum with two minutes recovery. The results indicated that reliability of EMG was higher within a single testing session compared to between different test days.

Research on the reliability of EMG has also been conducted on the hamstring muscle group. Fauth et al. (2010) examined EMG activity in the biceps femoris during maximal voluntary isometric contraction. Twenty four subjects performed maximal voluntary isometric knee flexion among other assessments on separate days. The authors reported near perfect reliability (r = 0.96) in the biceps femoris.

Kellis and Katis (2008) examined the reliability of EMG during isometric knee flexion. Eleven subjects performed maximal voluntary isometric contractions of the knee flexors on two separate days. They reported a mean interclass correlation coefficient of 0.94 for the EMG values during maximum isometric knee flexion. In addition, they reported a higher reliability in the biceps femoris compared to the semitendinosus. The present study examined EMG activity in the biceps femoris during maximal isometric knee flexion which is proven by previous literature to be a reliable measure.

Conclusion

Previous literature is inconclusive regarding the potential impact physical activity/training status and/or gender has on strength and fractioned reaction time. No published studies to date have examined both the fractions of reaction time as well as strength in the lower extremity in both genders. Nor have any adequately accounted for physical activity/training status. Therefore, the current study helps elucidate relationships between strength, physical activity status, gender, and fractioned reaction time in the hamstring muscle group. Information derived from this study can enhance current athletic talent evaluation and training paradigms.

CHAPTER THREE

Methods

The purpose of this study was to examine the relationships between strength, gender, physical activity, and the components of fractioned reaction time. All forms were approved by the University's Office of Human Research Ethics Institutional Review Board. (PI: Stewart Young, IRB#: 10-2016)

Subjects

Twenty-four subjects (12 males, 12 females) between 18-29 years of age were recruited for this study. All were required to be free from neurological disorders and lower extremity injuries for six months prior to data collection. Pregnant subjects were also excluded due to known joint laxity issues during pregnancy (Calguneri et al. 1982; Schauberger et al. 1996). Subjects were required to abstain from caffeine ingestion for 24 hours prior to testing (Clubley et al. 1979; Lieberman et al. 1987). All subjects read and signed an informed consent document and completed a brief health history form documenting current health/physical activity status as well as caffeine abstinence prior to participation.

Procedure

Physical activity level was self-reported by subjects and quantified as minutes of activity per week. Subjects were asked to provide their average number of minutes of activity per week for the past six months. If a range of activity levels was given, the average of the highest and lowest weekly values was used as their physical activity score.

Fractioned reaction time (TRT, PMT, and EMD) and strength were assessed during a single testing session using a maximal voluntary isometric hamstring contraction. Subjects were positioned prone on a padded table with the right thigh supported in 30° of flexion. A compression load cell (Honeywell Sensotec, Columbus, OH) was positioned at the calcaneous such that the lower leg was parallel to the ground (knee in 30° of flexion) and hamstring force (strength) could be measured (Fig. 1). Fractioned reaction time was assessed by having subjects contract the hamstrings isometrically in response to a visual (light) stimulus. The stimulus was presented at random time intervals after a verbal "ready" signal to reduce the likelihood of anticipation. Subjects were instructed to remain in a passive/relaxed state until the stimulus was presented, at which time they contracted the hamstrings maximally as quickly as possible. Each subject performed three "practice" trials to become familiar with the apparatus and to reduce a potential learning effect followed by five recorded trials with one minute of rest between trials to reduce the likelihood of fatigue.

Figure 1. Electromyographic testing method

Figure 1. Subject positioning during measurement of strength and reaction time (Blackburn et al. 2009).

Instrumentation

Electromyographic (EMG) activity, used to determine PMT and EMD, was measured using a preamplified/active surface EMG electrode configuration (DelSys, Inc., Boston, MA: interelectrode distance = 10 mm; amplification factor = 10,000 (20-450 Hz); CMMR @ 60 Hz> 80 dB; input impedance > 10^{15}//0.2Ω//pF) placed over the biceps femoris long head parallel to the direction of action potential propagation. Electrode location was determined via palpation and identification of the area of greatest muscle bulk within the muscle belly (Blackburn et al. 2009).

Fractioned reaction time was derived using computer algorithms employed via custom software (LabVIEW, National Instruments, Austin, TX). EMD was calculated as the time interval (ms) between the onset of hamstring EMG activity and force production of the load cell. The threshold for EMG onset was defined as two times the mean noise level over the 100 ms prior to presentation of the visual stimulus for a minimum of 50 ms to avoid erroneous identification (Blackburn et al. 2009). The threshold for the onset of force production was defined as five percent of the peak isometric hamstring force (Blackburn et al. 2009). PMT was calculated as the time interval (ms) between the presentation of the visual stimulus and the onset of hamstring EMG activity, as described above. TRT was calculated as the time interval (ms) between the presentation of the visual stimulus and the onset of force production, as described above.

Peak strength was recorded as the single highest force value measured during the five fractioned reaction time trials (N). Relative strength (N/kg) was also calculated by dividing the peak strength score by the subject's body mass (kg).

EMG and load cell data were sampled at 1000 Hz using The Motion Monitor motion capture software (Innovative Sports Training, Chicago, IL). Load cell data were lowpass filtered at 10 Hz (4^{th} order, zero-phase-lag, Butterworth) while EMG data were corrected for DC bias, bandpass (20-350 Hz) and notch (59.5-60.5 Hz) filtered (4^{th} order, zero-phase-lag, Butterworth), and smoothed using a

20 ms root-mean-square sliding window function to facilitate onset identification (Blackburn et al. 2009).

Statistical Design and Analyses

This quasi-experimental research design was a cross-sectional descriptive study. Physical activity, gender, and strength were the predictor variables and TRT, PMT, and EMD were the criterion variables. Descriptive statistics (X ± SD) were used to describe the subject personal characteristics (age, height, weight, physical activity), strength (isometric contractile force), and reaction time values (TRT, PMT, EMD). Reaction time (ms) was presented as the mean of five trials. Strength was presented in both absolute and relative units (i.e. peak force = N and relative force = N/kg) and was recorded as the largest single peak and relative isometric force generated during the five trials.

The reliability and precision of the strength and reaction time variables were determined by calculating intraclass correlation coefficients (ICC) and standard errors of the mean (SEM). The ICC provided the reliability of the measurement; the SEM provided an estimate of the precision of the measurement. A Repeated Measures Analysis of Variance (RepANOVA) was conducted on each variable to determine if there was a significant difference between trials. The results of the RepANOVA were then used to calculate the ICC and SEM values using the following equation (Denegar and Ball 1993):

Equation 1. Calculation of intraclass correlation coefficients:

$$\text{ICC (2,1)} = \frac{\text{BMS} - \text{EMS}}{\text{BMS} + (k - 1)\,\text{EMS} + k\,[(\text{TMS} - \text{EMS}) / n]}$$

Where. ICC = intraclass correlation coefficient; BMS = between subjects mean squares; EMS = error mean square; TMS = trial mean square; k = number of trials; n = number of subjects (Denegar and Ball 1993).

Equation 2: Calculation of standard error of the mean:

$$\text{SEM} = s\ \sqrt{1-r}$$

Where: SEM = standard error of the mean; *s* = standard deviation of the measurement; *r* = intraclass correlation coefficient (Denegar and Ball 1993).

Correlation Analysis

All bivariate and correlation analyses were reviewed with the following scaling of the relationship per Cohen (1988):

Weak correlation: $r \leq 0.29$

Moderate Correlation: r = 0.30 to 0.49

Strong Relationship: $r \geq 0.50$

Research Hypotheses and Associated Statistical Analyses

Hypothesis 1. To determine if there was a significant relationship between strength, physical activity, and EMD, bivariate correlations were conducted.

Hypothesis 1a*.* To determine if gender influenced these relationships, partial correlations, controlling for gender, were conducted.

Hypothesis 2. To determine if there was a significant relationship between strength, physical activity, and PMT, bivariate correlations were conducted.

Hypothesis 2a. To determine if gender influenced these relationships, partial correlations, controlling for gender, were conducted.

Hypothesis 3. To determine if there was a significant relationship between strength, physical activity, and TRT, bivariate correlations were conducted.

Hypothesis 3a*.* To determine if gender influenced these relationships, partial correlations, controlling for gender, were conducted.

The alpha level for all analyses was set at the $p < 0.05$ level of significance and all statistical analyses were completed using PASW version 18.0 (Chicago, IL).

CHAPTER FOUR

Results

Subjects

Twenty-four subjects (12 males, 12 females) volunteered to participate and completed the testing protocol. Table 2 provides a summary of the subject's personal characteristics.

Table 2

Subject personal characteristics (mean ± SD)

Variable	*Males (n = 12)*	*Females (n = 12)*	*Total (n = 24)*
Age	22.6 ± 3.2	22.5 ± 2.2	22.5 ± 2.7
Height (cm)	180.7 ± 5.9	166.0 ± 6.8	173.4 ± 9.7
Weight (kg)	76.8 ± 10.5	62.9 ± 11.5	69.8 ± 12.9
Physical Activity (min/wk)	280 ± 206	202 ± 71	241 ± 156

Pre-motor time (PMT), electromechanical delay (EMD), total reaction time (TRT), and strength (defined as peak force [N] and relative force [N/kg]) were measured for each subject during each of five trials. Table 3 provides the means and standard deviations for the reaction time and strength variables. An independent samples t-test was conducted on each variable in Table 3 to compare the differences between males and females. No difference between genders was observed for any of the fractioned reaction time variables but males displayed significantly greater peak and relative strength scores compared to females (Table 3).

Table 3

Fractioned reaction time and strength by gender (mean ± SD)

Variable	*Males (n = 12)*	*Females (n = 12)*	*Total (n = 24)*
PMT (ms)	187.6 ± 18.8	212.7 ± 40.3	200.1 ± 33.0
EMD (ms)	145.9 ± 36.3	156.3 ± 24.0	151.1 ± 30.6
TRT (ms)	333.5 ± 51.2	369.0 ± 41.7	351.2 ± 49.2
Peak Strength (N)	102.5 ± 31.5*	58.2 ± 16.9	80.4 ± 33.5
Relative Strength (N/kg)	1.40 ± 0.40*	0.90 ± 0.30	1.10 ± 0.40

Note. PMT = Pre-Motor Time; EMD = Electromechanical Delay; TRT = Total Reaction Time;
* $p < 0.05$.

Reliability and Precision

Repeated measures analysis of variance (RepANOVAs) were performed on each variable (PMT, EMD, TRT, peak strength, and relative strength) to determine the reliability of these measurements. No significant difference was detected between any of the trials (Table 4). The RepANOVAs were then used to determine intraclass correlation coefficients (ICC) and standard errors of the mean (SEM). Table 4 also displays the ICC and SEM for the reaction time and strength variables.

Table 4

RepANOVA results plus ICC and SEM values for each of the reaction time and strength variables (n=24)

Variable	*Critical F*	*p value*	*ICC*	*SEM*
PMT (ms)	0.583	0.622	0.34	49.16
EMD (ms)	0.555	0.630	0.56	28.83
TRT (ms)	1.098	0.354	0.63	40.73
Peak strength (N)	0.206	0.870	0.96	6.71
Relative strength (N/kg)	0.242	0.848	0.95	0.095

Note. RepANOVA = Repeated measures analysis of variance; ICC = intraclass correlation coefficient; SEM = standard error of the mean; PMT = Pre-Motor Time; EMD = Electromechanical Delay; TRT = Total Reaction Time.

Relationship Between Strength, Physical Activity, and Electromechanical Delay (EMD)

To evaluate the relationships between strength, physical activity, and EMD (*Hypothesis 1*), bivariate correlations were performed. As shown in Table 5, both relative strength and EMD had weak, non-significant relationships to physical activity ($p > 0.10$). However, higher peak strength was significantly correlated with higher physical activity levels ($r = 0.458$, $p = 0.024$).

Table 5

Bivariate correlations for strength (peak and relative), physical activity, and reaction time (PMT, EMD, TRT) (n=24)

	Peak Strength	*Relative Strength*	*PMT*	*EMD*	*TRT*
PA	0.458*	0.335	-0.294	-0.276	-0.371
Peak Strength	-	-	-0.335	-0.365	-0.455*
Relative Strength	-	-	-0.397	-0.288	-0.448*

Note. PA = physical activity; PMT = Pre-Motor Time; EMD = Electromechanical Delay; TRT = Total Reaction Time; *$p < 0.05$.

Relationship Between Gender and Electromechanical Delay (EMD)

To test the sub-hypothesis that gender influences the relationships between strength, physical activity, and EMD (*Hypothesis 1a*) partial correlations, controlling for gender, were performed (Table 6). After gender was controlled for, it can be seen that the significant relationship between physical activity and peak strength was negated. Specifically, the r value decreased from 0.458 ($p = 0.024$) to 0.401 ($p = 0.058$) therefore the peak strength: physical activity relationship then failed to reach the a-priori level of significance ($p < 0.05$).

Table 6

Partial correlations controlling for the effects of gender on physical activity, strength (peak and relative), and fractioned reaction time (PMT, EMD, TRT) (n=24)

	Peak Strength	*Relative Strength*	*PMT*	*EMD*	*TRT*
PA	0.401	0.245	-0.219	-0.244	-0.308
Peak Strength	-	-	-0.110	-0.342	-0.300
Relative Strength	-	-	-0.251	-0.235	-0.324

Note. PA = physical activity; PMT = Pre-Motor Time; EMD = Electromechanical Delay; TRT = Total Reaction Time.

Exploring gender relationships separately confirmed there were no significant relationships ($p > 0.05$) between physical activity, peak strength, relative strength, or EMD (Tables 7 and 8).

Table 7

Bivariate correlations for only female subjects (n=12)

	Peak Strength	*Relative Strength*	*PMT*	*EMD*	*TRT*
PA	-0.012	0.328	-0.319	0.284	-0.145
Peak Strength	-	-	0.163	-0.505	-0.132
Relative Strength	-	-	-0.193	-0.337	-0.380

Note. PA = physical activity, PMT = Pre-Motor Time, EMD = Electromechanical Delay, TRT = Total Reaction Time.

Table 8

Bivariate correlations for only male subjects (n=12)

	Peak Strength	*Relative Strength*	*PMT*	*EMD*	*TRT*
PA	0.484	0.237	-0.314	-0.373	-0.380
Peak Strength	-	-	-0.486	-0.286	-0.381
Relative Strength	-	-	-0.438	-0.189	-0.295

Note. PA = physical activity, PMT = Pre-Motor Time, EMD = Electromechanical Delay, TRT = Total Reaction Time.

Although female subjects showed a higher inverse relationship between relative strength and EMD compared to males (see Tables 7 and 8, respectively) no relationship attained statistical significance. Similarly, a higher inverse, but not significant, relationship was noted between relative strength and EMD ($r = -0.337$, $p = 0.283$) in females (Table 7) when compared to the same correlational pairing in males (Table 8) ($r = -0.189$, $p = 0.556$). To determine if the r values between males and females were significantly different, the r values were converted to z scores (Pallant 2007). The z scores were then inserted into an equation to calculate the observed value of z (z_{obs} score) as shown below (Equation 3).

Equation 3. Equation used to calculate Z_{obs} values:

$$Z_{obs} = \frac{z_1 - z_2}{\sqrt{\frac{1}{n1-3} + \frac{1}{n2-3}}}$$

Where. z_1 = z score for first group; z_2 = z score for second group; n1 = number of subjects in group 1; n2 = number of subjects in group 2.

The Z_{obs} scores were declared significant if they were greater than or equal to 1.96 or less than or equal to -1.96 (Pallant 2007). Table 9 displays the Z_{obs} values for the relationships between physical activity, peak force, relative force, and EMD. As can be seen in Table 9, none of the Z_{obs} scores were statistically significant, hence there were no significant differences between males and females for the relationships between strength, physical activity, and EMD.

Table 9

Calculated Z_{obs} scores for strength (peak and relative), physical activity, and EMD

Relationship	*Z_{obs} score*
Peak Strength and EMD	0.56
Relative Strength and EMD	0.33
PA and EMD	-1.46

Note. EMD = electromechanical delay, PA = physical activity, Z_{obs} = observed value of z.

Relationship Between Strength, Physical Activity, and Pre-motor Time (PMT)

To evaluate the relationships between strength, physical activity, and PMT (*Hypothesis 2*), bivariate correlations were performed (Table 5). While statistical significance was not achieved for any relationship, the inverse relationship between relative strength and PMT approached significance ($r = -0.397$, $p = 0.055$).

Relationship Between Gender and Pre-motor Time (PMT)

To test the sub-hypothesis that gender influences the relationships between strength, physical activity, and PMT (*Hypothesis 2a*) partial correlations, controlling for gender, were performed

(Table 6). This correction weakened the statistical significance found in the uncorrected bivariate analysis between both peak and relative strength and PMT (i.e., p value increased from 0.055 to 0.251). When genders were examined separately, a very weak positive relationship was observed between peak strength and PMT for females ($r = 0.163$, $p = 0.613$; Table 7) whereas a moderate inverse trend was seen for males ($r = -0.486$, $p = 0.109$; Table 8). The relationship between relative strength and PMT also differed between females ($r = -0.193$, $p = 0.548$; Table 7) and males ($r = -0.438$, $p = 0.154$; Table 8). To determine if the r values between males and females were significantly different, the r values were converted to z scores (Equation 3). Again, none of the Z_{obs} scores were statistically significant (Table 10), therefore, there were no significant differences between males and females for the physical activity, strength, and PMT relationships.

Table 10

Calculated Z_{obs} scores for strength (peak and relative), physical activity, and PMT

Relationship	*Z_{obs} score*
PA and PMT	0.01
Peak Strength and PMT	-1.38
Relative Strength and PMT	-0.58

Note. PA = physical activity; PMT = pre-motor time, Z_{obs} = observed value of z.

Relationship Between Strength, Physical Activity, and Total Reaction Time (TRT)

To evaluate the relationships between strength, physical activity, and TRT (*Hypothesis 3*), bivariate correlations were performed. As shown in Table 5, significant inverse relationships were observed between peak strength and TRT ($r = -0.455$, $p = 0.026$) and relative strength and TRT ($r = -0.448$, $p = 0.028$). These relationships are also displayed as scatterplots in Figures 2 and 3. In addition, the relationship between physical activity and TRT demonstrated a trend toward significance ($r = -0.371$, $p = 0.074$).

Figure 2. Scatterplot of relationship between peak strength and TRT (n=24)

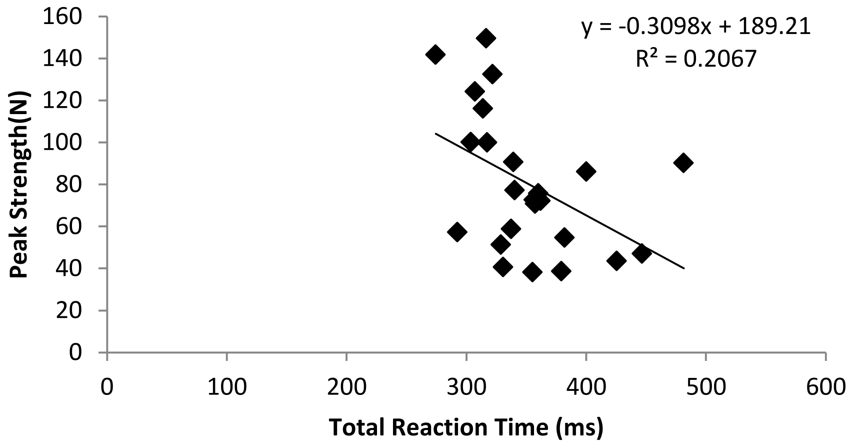

Figure 2. TRT = total reaction time.

Figure 3. Scatterplot of relationship between relative strength and TRT (n=24)

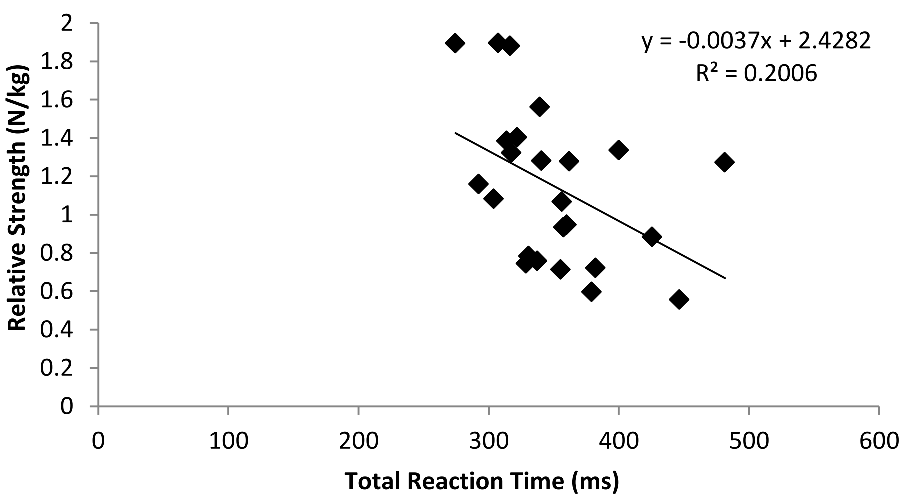

Figure 3. TRT = total reaction time.

Relationship Between Gender and Total Reaction Time (TRT)

To test the sub-hypothesis that gender influences the relationships between strength, physical activity, and TRT (*Hypothesis 3a*) partial correlations, controlling for gender, were performed (Table 6). Contrary to the bivariate analysis, the relationship between peak strength and TRT was rendered non-significant (Table 6: r = -0.300, p = 0.165). When genders were examined separately

(Tables 7 and 8), females displayed a lower inverse relationship between peak strength and TRT ($r = -0.132$, $p = 0.682$) compared to males($r = -0.381$, $p = 0.222$). To determine if the r values between males and females were significantly different, the r values were converted to z scores (Equation 3). As with the preceding z score transformations, no significant differences were found for the r values between genders (Table 11).

Table 11

Calculated Z_{obs} scores for strength (peak and relative), physical activity, and PMT

Relationship	*Z_{obs} score*
PA and TRT	-0.54
Peak Strength and TRT	-0.57
Relative Strength and TRT	0.20

Note. PA = physical activity; TRT = total reaction time, Z_{obs} = observed value of z.

Similarly, the significant relationship between relative strength and TRT was rendered insignificant when examined with a partial correlation controlling for gender (Table 6) ($r = -0.324$, $p = 0.131$). When males and females were examined separately, female subjects demonstrated a higher inverse relationship between relative strength and TRT ($r = -0.380$, $p = 0.223$) compared to males ($r = -0.295$, $p = 0.352$). To determine if the r values between males and females were significantly different, the r values were converted to z scores (Equation 3). As with the preceding z score transformations, no significant differences were found for the r values between genders (Table 11).

CHAPTER FIVE

Discussion

The primary purpose of this study was to explore the relationship between strength, physical activity, and fractioned reaction time. A secondary purpose of this study was to determine if gender influenced these relationships. The results indicated that there was a significant inverse relationship between peak strength and TRT ($r = -0.455$, $p = 0.026$) as well as between relative strength and TRT ($r = -0.448$, $p = 0.028$). No other statistically significant relationships were found. In addition, gender influenced these relationships by rendering them insignificant when examined with a partial correlation analysis. However, no significant difference in the relationships between males and females was observed for any relationship examined. The following discussion focuses on the aforementioned results followed by a review of strengths and limitations of the study.

Relationship Between Strength and Fractioned Reaction Time

As defined earlier, fractioned reaction time consists of two variables: pre-motor time (PMT) and electromechanical delay (EMD). Pre-motor time is defined as the time delay between when a stimulus is presented and when electrical activity in the muscle is detected. Electromechanical delay is defined as the time delay between when electrical activity in the muscle is detected and when force is produced by the muscle. Together, these two variables make up total reaction time (TRT).

Relationship between strength and TRT.

The first aim of this study was to examine the relationship between strength and fractioned reaction time. A significant inverse relationship was observed between both peak and relative strength and TRT (r = -0.448, p = 0.028; r = -0.455, p = 0.026, respectively) which suggests that when strength declines, regardless of body mass, total reaction time slows. Since TRT is composed of both PMT and EMD, it appears that PMT was potentially driving the inverse relationship found between relative strength and TRT (r = -0.397, p = 0.055) rather than EMD (r = -0.288, p = 0.173). While the relationship between relative strength and PMT was not statistically significant (observed power of only 0.502; Glantz 1999) it was physiologically significant. This study's correlational results concur with previous intervention studies which have shown that strength training increases EMG activity in the muscles trained as well as firing rate and fiber recruitment (Hakkinen and Komi 1986; Sale 1988). Previous research has also shown that greater levels of strength are due to larger fiber cross sectional area (Miller et al. 1993; Sale et al. 1987; Schantz et al. 1983). Additionally, Andreassen and Arendt-Nielsen (1987) found that muscles with larger cross sectional area have faster motor unit conduction velocity. This may explain the physiologically significant relationship between relative strength and PMT because larger muscle fibers are better able to conduct action potentials. Sale et al. (1982) and Sale et al. (1983) found that a 10 - 12 week resistance training program increased motoneuron excitability during voluntary contraction.

Based on the results of the present study, it is unclear whether the decrease in PMT associated with an increase in relative strength is centrally or peripherally driven. Aagaard (2003) stated that increases in strength as a result of resistance training have been shown to result in elevated descending motor drive from the suprapspinal centers. This could be due to an increase in the excitability of spinal motor neurons as a result of increased sensitivity to the neurotransmitter acetylcholine (Aagaard 2003). A potential peripheral mechanism for decreased PMT is that larger (and therefore stronger) muscle fibers are better able to propagate action potentials and are more sensitized to neurotransmitter release at the motor endplate (Andreassen and Arendt-Nielsen 1987; Sale et al. 1983).

It is unclear which component of TRT was the driving factor when examining the relationship between peak strength and reaction time since both PMT and EMD had similar moderate, non-significant inverse relationships to peak strength ($r \le 0.365$, $p \ge 0.079$). It seems counterintuitive that there was a significant inverse relationship between strength and TRT without a significant inverse relationship between strength and at least one of the components of TRT (PMT or EMD). Unfortunately, the scope of this study does not allow for speculation as to why that finding might have occurred but it does provide an interesting topic for future research.

Relationship between strength and EMD.

Only one study (Viitasalo and Komi 1981) has examined the relationship between reaction time and strength. While Viitasalo and Komi (1981) found that there was no relationship between strength, PMT, and TRT, they did find a significant inverse relationship between strength and EMD ($r = -0.62$, $p < 0.001$). It is important to note that Viitasalo and Komi (1981) defined strength as peak torque (and not peak force production as in the present study). Interestingly, although a significant inverse relationship was discovered between peak strength and TRT in the present study, no significant relationship was observed between peak strength and either PMT or EMD. However, the relationship between peak strength and EMD approached significance ($r = -0.365$, $p = 0.079$). This discrepancy in results could be due to the different definitions of strength (i.e., peak torque in Viitasalo and Komi (1981) vs. peak isometric force production in the present study).

Additionally, Bell and Jacobs (1986) reported significantly shorter EMD in groups with greater strength levels. However, Blackburn et al. (2009) did not find a difference in EMD even though subjects had significantly different rates of force production. While peak force data were not reported by Blackburn et al. (2009), their finding supports the position that an increase in strength does not decrease EMD because differences in strength were observed between groups but no differences in EMD. Although a literature review was inconclusive, the lack of a significant relationship between peak force and EMD in the present study suggests strength is not related to EMD.

When comparing the results of these studies, it is important to note the variance in muscle group examined. Viitasalo and Komi (1981) examined the vastus lateralis muscle while Bell and Jacobs (1986) examined the biceps brachii and the biceps femoris was examined by Blackburn et al. (2009) and in the present study. Previous studies have shown that muscle fiber cross sectional area as well as fiber type distribution significantly differs between muscle groups (Miller et al. 1993; Sale et al. 1987; Schantz et al. 1983). This makes comparisons between these studies difficult because fiber cross sectional area and fiber type can influence strength and fractioned reaction time (Miller et al. 1993; Sale et al. 1987; Schantz et al. 1983). Additionally, variability in fiber type distribution has been demonstrated between the vastus lateralis, biceps femoris, and biceps brachii (Johnson et al. 1973).

To eliminate body mass as a potential confounding factor in the present study, strength was normalized to body mass by examining relative strength (N/kg). The bivariate relationship between EMD and relative strength was not significant ($r = -0.288$, $p = 0.173$). This finding is in disagreement with Viitasalo and Komi (1981) who found that strength and EMD were significantly related (although strength was defined as peak torque by Viitasalo and Komi [1981]). Defining strength in relative units (N/kg) suggests that the relationship between EMD and strength demonstrated by Viitasalo and Komi (1981) may have been due to body mass variations of the subject population rather than strength per se.

Relationship Between Strength and Physical Activity

A significant bivariate relationship was found between peak strength and physical activity ($r = 0.458$, $p = 0.024$), suggesting that higher levels of strength were seen in individuals with higher levels of physical activity (defined as minutes of activity per week). This result is to be expected and confirmed previous literature that showed increased physical activity levels were associated with increased muscular strength (Buenen et al. 1992; Katzmaryzk et al. 1998)

Relationship Between Physical Activity and Fractioned Reaction Time

The second aim of this study was to examine the relationship between physical activity and fractioned reaction time. Bivariate correlations were performed between physical activity (min/week), strength (peak force), relative strength (relative force), pre-motor time (PMT), electromechanical delay (EMD), and total reaction time (TRT).

While physical activity and the components of fractioned reaction time (PMT, EMD, and TRT) did not individually reach statistical significance, TRT approached significance ($r = -0.371$, $p = 0.074$). This trend makes sense in light of the results that strength significantly correlated with TRT ($r = -0.455$, $p = 0.026$) and physical activity significantly correlated with peak strength ($r = 0.458$, $p = 0.024$). As mentioned in chapter two, much of the previous research conducted on the topic of physical activity and reaction time focused on the elderly and improving injury risk (Botwinick and Thompson 1968; Panton et al. 1990; Rooks et al. 1997; Spirduso 1975; Spirduso and Clifford 1978). These studies have been inconclusive as to whether or not physical activity improves reaction time. In addition, the reaction time tasks were simple and not analyzed utilizing the integrated technology used in the present study.

Gender Influences

The third aim of this study was to determine if gender influenced the relationships between strength, physical activity, and fractioned reaction time. Relationships between strength and physical activity, strength and TRT, and relative strength and TRT were all reduced to non-significant relationships when gender was partialed out of the correlations ($r \leq 0.401$, $p \geq 0.058$), thereby suggesting a gender difference may be present.

Relationship between peak strength and physical activity.

Even though partialing out gender resulted in only a minimal decrease in the correlation values (r decreased from 0.458 to 0.401), this decline rendered the partial correlation non-significant ($p = 0.058$). However, the z_{obs} scores were non-significant, indicating that there was no difference in r values between genders. This finding suggests that gender does, to some degree influence the relationship between physical activity and peak strength but does there is no difference in the relationship between physical activity and peak strength in males and females. This confirms previous literature that states there is no difference in physical activity levels between genders (CDC BRFSS 2007; Pratt et al. 1999). Likewise, no difference was found for physical activity levels between genders in the sample used in this study.

Relationship between strength and TRT.

Similar to the peak strength: physical activity relationship, when gender was controlled, the significant relationship between peak strength and TRT was rendered non-significant ($r = -0.300$, $p = 0.165$). This pattern was repeated for the relationship between relative strength and TRT when controlling for gender (p value increased from 0.028 to 0.130). Although the calculated z_{obs} scores confirmed a non-significant difference between bivariate and partial correlations, is should be noted that a sample size of at least $n = 20$ is recommended for accurate z_{obs} scores (Pallant 2007). Hence, lack of statistical significance when gender was controlled for is important to note because it suggests future fractioned reaction time studies should be gender specific.

Relationship between strength and PMT.

The relationship between peak and relative strength and PMT was not statistically significant when analyzed with bivariate or partial correlations ($p \geq 0.055$); suggesting PMT is not influenced by strength. As with TRT, the near significant trend between relative strength and PMT ($r = -0.397$, $p = 0.055$) was eliminated when gender was partialed out ($r = -0.251$, $p = 0.247$). The influence that gender had on these relationships is further demonstrated when the relationships were examined separately by gender. The relationship between peak strength and PMT in males was $r = -0.486$ ($p = 0.109$) compared to $r = 0.163$ ($p = 0.616$) in females. While it was interesting to find that the direction of the relationship differed between genders, neither correlation per gender was statistically significant. These discrepancies could be due to the large difference in mean peak strength values in males (102.5 ± 31.5 N) compared to females (58.2 ± 16.9 N) and the small sample size in each gender (n=12).

Relationship between strength and EMD.

Weak non-significant relationships existed between peak strength and EMD with and without controlling for gender ($r \leq 0.365$, $p > 0.05$). The large difference in r values seen when the relationships were examined in each gender separately remained non-significant, but the females did exhibit a stronger inverse association than the males ($r = -0.505$ vs. $r = -0.286$, respectively). Despite the r values being almost double that of the males, the z_{obs} scores did not show a significant difference. The same outcomes were repeated for the relationship comparisons between relative strength and EMD. Thus, it seems apparent that neither peak nor relative strength is associated with EMD, with or without controlling for gender.

Since the current study was the first to examine the influence of gender on the relationship between strength and EMD, only comparisons to similar studies can be made. The results of the current study are not in agreement with Viitatsalo and Komi (1981) or Bell and Jacobs (1986) who found a significant relationship between peak strength and EMD. A potential explanation for the divergent results between the current study and Viitasalo and Komi (1986) is that both genders were included in the present study whereas Viitasalo and Komi (1986) examined only males. The discrepancy between the present study and Bell and Jacobs (1986) could be due to the fact that their sample size was more than triple the current size, allowing for greater power to detect significance.

Summary

A gender influence was observed on the relationships between peak and relative strength and TRT as well as the relationship between peak strength and physical activity. However, the relationships were not significantly different between genders for any comparisons. While no significant gender differences were noted, trends between males and females were observed. One possible explanation for the gender influence and trends seen is the fact that males and females had different peak and relative strength scores for the hamstring muscle group tested. Even when strength was normalized for body mass, males still had higher relative strength scores (1.34 ± 0.41 N/kg males vs. 0.94 ± 0.28 N/kg females). An independent samples t-test used to compare the relative strength scores between genders and found the relative strength scores to be statistically different ($t[22] = 2.805$, $p = 0.01$). The gender differences in both peak and relative strength are supported by several previous studies (Miller et al. 1993; Komi and Karlsson 1978; Maughan et al. 1983).

Miller et al. (1993) and Staron et al. (2000) examined differences in muscle fiber characteristics in both genders and found that males have larger cross sectional fiber area than females. Miller et al. (1993) examined the biceps brachii and vastus lateralis muscle groups while Staron et al. (2000) only examined the vastus lateralis. Both studies conclude that a larger muscle fiber cross sectional area in males is the reason for the increased peak and relative strength. Larger cross sectional area allows for greater cross bridge interaction between actin and myosin and therefore greater strength. It is likely that the differences in relative strength in the hamstring muscle group observed in the present study were due to differences in fiber cross sectional area (Miller et al. 1993; Staron et al. 2000).

However, previous studies have also shown no difference in relative strength between genders for certain muscle groups (Wilmore 1974; Levine et al. 1984). Wilmore (1974) found that females displayed greater relative leg strength (leg press) compared to males but weaker upper body relative strength (elbow flexion). Levine et al. (1984) found that females were only weaker in relative elbow flexion strength but measured similar to males in all other relative strength measures. It appears that strength differences between genders are specific to the muscle group examined. To allow for more accurate comparisons, future research should to explore the relationship between strength and fractioned reaction time in various muscle groups.

Strengths and Limitations

The major strength of this study was the inclusion of both males and females. Previous research examining neuromuscular properties and reaction time in particular have only studied male subjects (Viitasalo and Komi 1981). However, some literature has opened up the possibility that gender differences may exist in reaction time (Bell and Jacobs 1986; Morris and Beaudet 1980). Thus, the exploration of gender influences on fractioned reaction time was novel.

A strength and potential weakness of this study was the wide range of physical activity levels and maximal strength of the participants. Physical activity levels ranged from 90 minutes per week to 690 minutes per week in the subjects studied and strength measures spanned a wide range from 38 N to over 140 N. While this allowed for a more diverse sampling of the population, the variability may have reduced the ability to detect significant gender influences.

The small subject sample, cross sectional design, and correlational analysis also posed limitations. A larger sample size would have enabled more statistical power, and possibly allowed for control of strength and physical activity differences between subjects. The cross sectional design of the study combined with the correlational analysis allowed the relationships between variables to be explored but conclusions regarding causality could not be made.

The self-report of caffeine may have been a limitation because subjects were required to abstain from caffeine ingestion 24 hours prior to testing. Some subjects may have inadvertently ingested caffeine the afternoon before and not associated it as 24 hours before because it was a previous day. Additionally, subjects may have unknowingly ingested foods, beverages, or medications that contained caffeine. Lastly, while time of day has been shown to have no effect on reaction time (Frewer and Hindmarch 1988), it has been demonstrated that alertness and arousal level can impact reaction time (Brebner and Welford 1980). Subjects that participated in testing in the morning without adequate rest the night before may have had lower arousal levels than subjects who were tested later in the day.

An additional limitation was not assessing body composition to gain a more accurate representation of relative strength. Relative strength normalized to fat free mass potentially could have been a variable of significance.

Finally, leg dominance was a potential limitation to the present study since testing was only conducted on the right leg. However, previous research has shown that strength does not differ between dominant and non-dominant legs (Lindstrom et al. 1995) and only two subjects reported their dominant leg as the left leg.

Future research should continue to investigate the role of gender on fractioned reaction time in various muscle groups. Gender differences may be more apparent in smaller muscle groups as opposed to the larger muscle groups such as was used in the current study. Also, investigating by different levels of physical activity status or strength may clarify the role gender plays in fractioned reaction time.

CHAPTER SIX

Summary and Conclusions

Summary

The primary purpose of this study was to examine the relationship between strength, physical activity, and fractioned reaction time. A secondary purpose of this study was to determine if gender influenced the relationships between strength, physical activity, and fractioned reaction time.

The findings indicated that there was a significant inverse relationship between peak strength and TRT ($r = -0.455$, $p = 0.026$). The data also showed a significant inverse relationship between relative strength and TRT ($r = -0.448$, $p = 0.028$). These findings indicate that peak strength accounts for 20.7% of the variation in TRT and that relative strength accounts for 20.1% of the variation in TRT. These findings disagree with Viitasalo and Komi (1981) who found that strength is significantly related to EMD ($r = -0.62$) and not TRT ($r = -0.31$).

When the relationships between strength, physical activity, and fractioned reaction time were examined with a partial correlation controlling for gender, a gender influence was observed. Controlling for gender weakened all the relationships including the relationship between relative strength and TRT as well as the relationships between peak strength and TRT and peak strength and physical activity, which it rendered non-significant. The calculated z scores yielded non-significant results between males and females, indicating that gender does influence the relationships but there is no significant difference between males and females in the strength of the relationships.

Conclusions

Based on the results, the following hypotheses were addressed:

Hypothesis 1. There will be a relationship between strength, physical activity, and electromechanical delay (EMD).

This hypothesis was rejected because no significant relationship existed between strength, physical activity, and EMD.

Hypothesis 1a. Gender will not influence the relationship between strength, physical activity and EMD.

This hypothesis was accepted because gender did not significantly influence the relationship between strength, physical activity, and EMD.

Hypothesis 2. There will be no relationship between strength, physical activity, and PMT.

This hypothesis was accepted because no significant relationship was found between strength, physical activity, and PMT.

Hypothesis 2a. Gender will not influence the relationship between strength, physical activity, and PMT.

This hypothesis was accepted because gender did not significantly influence the relationship between strength, physical activity, and PMT.

Hypothesis 3. There will be a relationship between strength, physical activity, and TRT.

The first part of this hypothesis was accepted because a significant relationship was observed between peak strength and TRT as well as between relative strength and TRT. However, the second part of this hypothesis was rejected because no relationship existed between physical activity and TRT.

Hypothesis 3a. Gender will not influence the relationship between strength, physical activity, and TRT.

This hypothesis was rejected because a significant gender influence on the relationship between strength, physical activity, and TRT was observed.

Practical Application

Reaction time remains one of the most crucial factors of performance in a number of athletic events. The indication that total reaction time is related to strength lends even more importance to the need to increase strength in athletes. This finding might be of use to strength and conditioning professionals who are seeking to improve the reactive capabilities of their athletes without wasting valuable training time on reactive training drills. In addition, this finding can also provide information for talent evaluation professionals by identifying which athletes possess both high levels of strength and high reactive capabilities.

Recommendations for Future Research

Future research should continue to explore the relationship between strength and TRT demonstrated in the present study. The present study raised questions as to why this relationship exists and a study design involving a strength training program to increase strength compared to a control group would allow for answers to these questions. Additionally, future research should further examine the impact of gender on both relative and peak strength as well as reaction time. The differences in r values observed in the present study lead one to believe that a gender effect is possible. However, the differences in r values were not significantly different, possibly due to a small sample size and/or the large variability in training status and maximal strength of the hamstring group. Future research should analyze these relationships with a sample size large enough to accurately determine significance (at least n=20 per group). Future research should also examine the relationship between strength and fractioned reaction time while including the variables of relative strength normalized to fat free mass as well as muscle fiber cross sectional area. The variables examined should also be muscle group specific so that comparisons can be made without the confounding factor of difference in muscle characteristics. Finally, as sports performance training becomes more popular in this country, future research should examine the effects of strength training compared to reactive training on reaction time tasks. This could provide answers as to whether specific training to improve reaction time is even necessary and may save valuable training time.

APPENDIX A

Personal History Questionnaire

1. How would you rate your general state of well-being today? (circle number)

←---→

1	2	3	4	5
Very good	Good	Average	Bad	Very Bad

2. Have you been sick within the past week? YES NO

   If you answered “yes”, please describe the nature of your illness:

3. Did you exercise today? YES NO

   If you answered “yes”, please briefly describe what you did and for how long:

   If you answered “yes” please rate the intensity of today’s workout by circling the appropriate number below:

←---→

1	2	3	4	5
Very easy	Easy	Average	Hard	Very Hard

4. Over the last 6 months, on average, how many minutes of exercise/physical activity do you engage in per week? (e.g. 3 days per week, 30 minutes per session)

5. What types of activities/exercises do you generally engage in, check all that apply:

____ Aerobics ____Weight Lifting ____Plyometrics ____Other (please explain)

____

6. Did you smoke or use nicotine in any form today? YES NO

If you answered yes, please list when you last smoked/had nicotine and how much:

____

7. Have you ingested ANY caffeine in the past 24 hours (i.e. coffee, tea, soda, etc)? YES NO

If you answered yes, please list how much you have had today and when:

____

8. Do you know which leg is your dominant (strong) leg? YES NO

If you answered yes, which leg is it? _______________

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