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Electromyography study of muscle fatigue during isometric exercises in swimmers and non-swimmers

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ELECTROMYOGRAPHY STUDY OF MUSCLE FATIGUE DURING ISOMETRIC EXERCISES IN SWIMMERS AND NON-SWIMMERS

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APPROVAL OF THESIS/DISSERTATION

We, the faculty supervising the work of Tiffany Aeling, affirm that the thesis/dissertation, *Electromyography Study of Muscle Fatigue during Isometric Exercises in Swimmers and Non-- Swimmers,* meets the high academic standards for original scholarship and creative work established by the Biological Sciences Program and College of Science. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

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LIST OF ABBREVIATIONS

1. Posterior Deltoid: PD

2. Upper Trapezius: UT

3. Middle Trapezius: MT

4. Lower Trapezius: LT

5. Infraspinatus: INF

6. Serratus Anterior: SA

7. Lumbar Erector Spinae: ES

8. Electromyography: EMG

9. Surface Electromyography: sEMG

10. Slope of Median Frequency: SMDF

ABSTRACT

The use of electromyography (EMG) techniques offer strong evaluation of musculature fatigue during activity in different exercises. Studies show that EMG can be used to monitor fatigue patterns in muscles composing the upper extremities and thoracic areas of the human body by analyzing median frequency values. Advances in muscle fatigue research have been critical for improving rehabilitation programs for patients with musculoskeletal conditions. Despite these developments, many collegiate athletes are still at high risk for muscle injury on and off the playing field. Therefore, in order to help reduce injury numbers, it is important that current research focus on the fatigue rates over time in muscles involved for critical movements within specific sports. This study tested fatigue patterns in muscles of the posterior shoulder and lower lumbar using surface EMG (sEMG). Thirty one female subjects between the ages of 18-23 (11 swimmers and 23 non-swimmers) with no previous shoulder problems recorded in the past year were evaluated. Seven different muscles were tested including the posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), infraspinatus (INF), serratus anterior (SA), and the erector spinae (ES). Two isometric exercises were conducted with the subject's dominant arm at horizontal abduction of the shoulder joint at 90° ("T"), and at horizontal abduction of the shoulder joint at 135° ("Y"). The slope of the median frequency was used to evaluate the muscle fatigue of all seven muscles studied. Results demonstrate that the muscles of non-swimmers fatigue more rapidly than those of the swimmers, but only at the 90° position. Results also show that there is significant difference in fatigue rates in the two groups in the UT and LT at 135°, and the PD at 90°. These findings will help specialists develop appropriate rehabilitation programs for collegiate swimmers focusing on muscles involved in the recovery and reach phases of a swimming stroke. This could ultimately aid in producing stronger collegiate swimmers and fewer shoulder related injuries.

CHAPTER 1

INTRODUCTION

In the 2013-2014 academic year there were a total of 12,333 female NCAA student athletes in the sport of swimming and diving. Of that total 5,464 swimmers participated at the Division 1 level (Irick, 2014). Past studies show that competitive swimming creates a tremendous amount of stress on the upper extremities, due to the fact that 90% of the forward propulsive power is generated from the repetitive stroke rotations during activity (Heinlein & Cosgarea, 2010).

It is estimated that the average competitive swimmer will swim 65,000-85,000 yards during one week of practice, depending on their stroke specialty (Heinlein & Cosgarea, 2010). An average NCAA Division 1 season will start in September and end in March of spring semester after the NCAA championship competition (Irick, 2014). This averages to 28 total weeks in a swim season, and more than 1,848,000 total yards by the end of the year. On average depending on athlete demographics, a swimmer will take between 8-10 strokes per 25-yard pool lengths (Heinlein & Cosgarea, 2010). This results in over 750,000 strokes in an entire season, and some swimmers continue to practice after the collegiate season has ended, racking up over 1 million strokes in a year (Heinlein & Cosgarea, 2010; Wolf et al., 2009; Weldon and Richardson 2001).

In addition to water activity, there is also strength and conditioning in the weight room, and dry-land activities that swimmers participate in to increase their strength for in-water training (Wolf et al., 2009). These activities can lead to further stress on the body, and even more to the upper extremities. In a study performed by Wolf et al. 2009, injury patterns were recorded over a 5-year period on 50 athletes that participated on Iowa's Women's Swimming and Diving

Team. Results showed that there were a total of 76 injuries reported during the season, and when breaking down those injuries it showed that the in water swimming practice accounted for 60.5% of injuries, and 28% percent of the reported injuries were from strength training activities on land. Of the total injuries, 36% of the complaints were shoulder and upper arm related. Four of the females that complained of shoulder injury, ended up undergoing multiple shoulder surgeries due to the seriousness of the injury. One female swimmer ended up retiring after her second season because of the repeated injuries and multiple surgeries. Studies like these make it clear on why 90% of complaints by swimmers pertain to the shoulder, and why shoulder pain is highest musculoskeletal complaint amongst competitive swimmers (Heinlein & Cosgarea, 2010; Weldon & Richardson, 2001).

The term “swimmers shoulder” is commonly used to describe pain in the shoulder joint when injury occurs in these athletes. This refers to some type of shoulder impingement, most commonly a type of tendinopathy around the glenohumeral joint due to the repetitive shoulder use. Common types of shoulder pain in swimmers include supraspinatus tendinopathy, rotator cuff tendonitis, bicep tendonitis, shoulder instability, and labral tears (Heinlein & Cosgarea, 2010; Sein et al., 2010). There is no surprise that due to the complexity of shoulder anatomy that there are large amounts of different shoulder pathologies especially in overhead athletes (Szucs, et al., 2009). In a study performed by Sein et al. (2010), 80 elite swimmers participated in research that involved evaluating shoulder pain. Of these 80 subjects tested, 90% reported some type of shoulder pain. Of those subjects that reported pain, 69% showed supraspinatus tendinopathy after having further workup with magnetic resonance imaging performed (MRI) (Sein et al., 2010).

Labral tears are another common injury sustained by swimming athletes, and treatments for this diagnosis have been minimally researched. Swimmers that develop this pathology are have hours of rehabilitation and possibly surgery. Usually even with extensive care of the shoulder, the ultimate outcome of this diagnosis is retirement of the athlete. Results conducted in a study performed by Brush et al. 2007 supported prior studies that swimmers develop shoulder pain due to a large variety of different pathologies. Brush researched the return to date statistics in elite swimmers that had shoulder surgery, due to a therapy resistant injury. Return to date refers to the day in which an athlete is cleared by their doctor to be able to participate in their sport. They found that only 56% of these athletes returned to competitive swimming after the surgery and only 44% of these athletes were able to go back to swimming without any shoulder pain (Brush et al., 2007). The other 44% never returned to competitive swimming due to the pain associated with the surgery.

Biomechanics of Swim Strokes

In collegiate swimming there are four stroke styles that athletes can compete in at the NCAA level including: butterfly, backstroke, breaststroke and freestyle. Each stroke has different technique styles, and require the firing of different muscles to perform each stroke correctly. Many injuries have been evaluated because of improper techniques during swimming. Fatigue in muscles during training can lead these stroke kinematic changes, and may ultimately may result in injury (Ebaugh et al., 2006). This is a major reason why coaches spend hours perfecting swimming technique in individuals. Each phase in every stroke has contraction patterns of different muscles that allows for forward propulsion in the water (Colwin, 2002). These muscles in the upper body play important roles in the breathing, propulsion, and stabilizing the athlete during swimming (Lomax et al., 2015). During practice, the freestyle stroke makes up the majority of the yardage performed during different workout sets, and is the most researched of all four styles (Heinlein & Cosgarea, 2010). Several muscles that are involved in the forward propulsion of an athlete in the water during this freestyle stoke which include, but are not limited to: the posterior deltoid (PD), upper and lower trapezius (UT, LT), infraspinatus (INF), and serratus interior (SA), supraspinatus, pectoralis major, and latissimus dorsi (Colwin, 2002). EMG studies have been performed on swimmers to research which muscles are firing at different times in each phase of the 4 strokes. The freestyle stroke will be concentrated on most due to its high yardage volume performed by swimmers. The freestyle motion can be broken down into 8 different phases which include the early recovery, mid-recovery, late recovery, glide and reach, early pull through, mid pull through, and late pull through, and end of pulling phases (Figure 1).

Freestyle Muscle Activation in Different Phases

As a swimmer completes one complete stroke and starts to bring their hand out of the water for the next one, they are beginning the start of the early recovery stage. Recovery stages of the stroke are faster than the pull through stages because there is no water resistance taking place. During this stage the PD and the MD are firing in order to get the hand out of the water to begin the next phase of the recovery portion with abduction of the humerus (Heinlein & Cosgarea, 2010). Muscle activation continues during the mid-recovery stage with the firing of the MD, UT, SA and INFRA. These muscles are being activated in order to rotate the scapula upward to begin the last phase of the recovery portion. During the late recovery stage the MD and SA are firing most in order to allow the hand to start the beginning of the glide phase as it begins to enter the water again. During the glide phase of the freestyle stroke, the UT and SA are firing to stabilize and rotate the scapula upward to start the pull through portion (Heinlein &

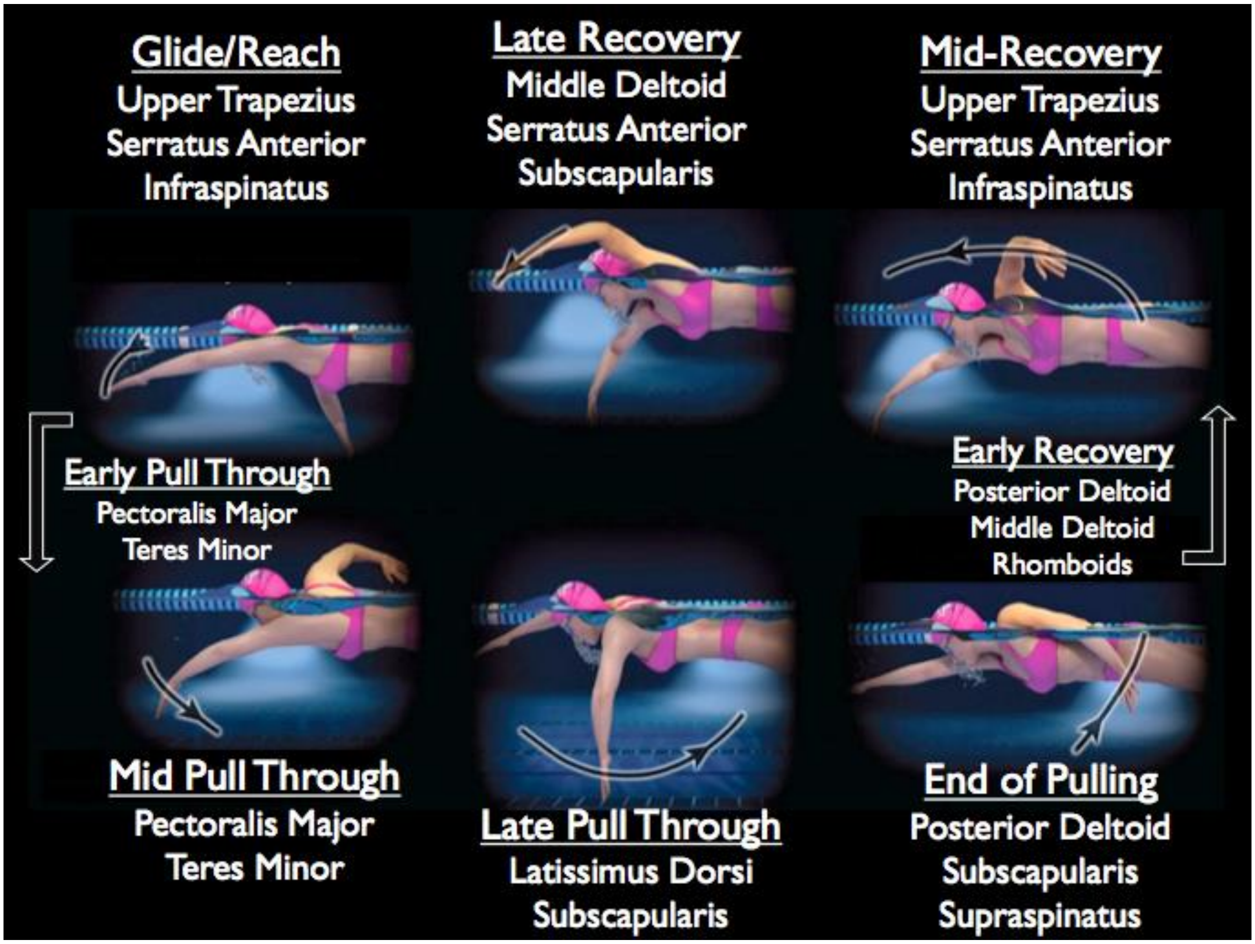


Figure 1. Different phases of the freestyle swim stroke, and major muscles activated at each stage. Figure modified from Heinlein & Cosgarea, 2010.

Cosgarea, 2010; Pink et al., 1991). When the hand reaches maximum forward extension during the glide phase, the beginning of the early pull through stage begins where there is internal rotation, extension, and adduction at the glenohumeral joint (Heinlein & Cosgarea, 2010; Pink et al., 1991). During this time, muscles including the pectoralis major and the teres minor are activated for continued internal rotation of the humerus. Throughout the rest of the mid pull, late, and end phases the SA, pectoralis major, latissimus dorsi work together to pull the body over the hand, almost working like a fulcrum (Colwin, 2002).

Muscle Physiology

Swimming is often considered a total body workout, which incorporates many different body movement and muscle activations in order to propel an athlete's body forward through the water. Understanding muscle physiology and mechanisms behind muscle contraction is important to be able to distinguish differences in muscle recruitment during different phases of the freestyle stroke.

Muscle Contraction

Muscle contraction begins with a stimulus that is received by the dendrites of somatic motor neuron. After a stimulus is received, an action potential is created and travels down the axon of the motor neuron until it reaches the axon terminal. The axon terminal is near the sarcolemma or the plasma membrane of a muscle fiber, where together they create a motor unit or the neuromuscular junction (Mader & Windelspecht, 2014). A motor unit is an alpha motor neuron, and all of the muscle fibers that it innervates (Scott et al., 2001). When the stimulus reaches the axon terminal, vesicles that contain acetylcholine (ACh) are released into the synaptic cleft, or the area in between the motor unit. Within the synaptic cleft there is an accumulation of sodium (Na^+) molecules, and on the inside of the muscle fiber there are large number of potassium (K+) molecules (Fox, 2014). Imbedded within the sarcolemma of the muscle fiber are nicotinic ACh receptors that are closed at the time of the release of ACh into the synaptic cleft. When released from the vesicles, ACh travels across the synaptic cleft and bind to these ACh receptors and open chemically gated channels. This creates the rush of sodium into the muscle fiber with depolarization occurring to produce a potential (Fox, 2014). This action potential will travel across the sarcolemma and will eventually propagate down the T-tubules within the myofibrils. The action potential will cause calcium (Ca+) channels that are located in the T-tubules to open and calcium will be released from the sarcoplasmic reticulum. After the release of Ca+ into the T-tubules, it will travel towards the thin actin filaments that are located in the sarcomere (Mader & Windelspecht, 2014).

Rearrangements of two different proteins that are attached to the thin actin filaments within a sarcomere are important for the continuation of a muscle contraction. At rest, a protein strand called tropomyosin is wrapped around the actin filament and covers the binding site for the thick myosin head which is the major player in the contraction process (Scott, Stevens, & Binder–Macleod, 2001). When the Ca+ ions from the sarcoplasmic reticulum are released, they bind to troponin, which is another protein that is also attached to the actin filament. When calcium binds to troponin, it causes the tropomyosin strand to shift and opens up the myosin-binding site on the actin filaments. At the same time the thick filaments with myosin heads are getting prepared to start what is known as the power stroke. One myosin filament strand has two heads, with one for the binding site on actin and one for the binding of adenosine triphosphate (ATP) that is needed to give energy for the upcoming contraction (Scott et al., 2001). At the beginning of the power stroke, ATP is used to move the myosin head out of position from the myosin filament before attachment to the actin filament. Energy is used for this process, and

ATP is hydrolyzed into adenosine diphosphate (ADP) and an inorganic phosphate (Pi). These molecules are attached to the myosin head as it attaches to the actin filament, and when attachment happens it creates a cross bridge (Fox, 2014). Pi is then released from the myosin head as it pulls on the actin filament towards the M-line of the sarcomere, creating the power stroke (Fox, 2014). During the power stroke, the ADP molecule is released. If enough Ca+ and ATP are present, then this process will continue when a new ATP will bind to the myosin head after the release of the ADP molecule. This will cause the myosin head to go back down into resting position before starting another power stroke. This entire process together creates the muscle contraction (Mader & Windelspecht, 2014).

Metabolism in Skeletal Muscle

Due to the unique qualities among muscle fibers, there are different ways that skeletal muscles metabolize in order to get the proper amount of energy to perform a contraction. As mentioned above, ATP is the first responder as an energy source during muscle contraction (Westerblad et al., 2010). Although ATP is the immediate source there is a limited intracellular storage available. Researchers have found that if the muscle was fully activated during a contraction, the ATP storage would be depleted within 2 seconds of activation (Sahlin et al., 1998). Due to the quick usage of ATP during initial muscle contraction there are alternative pathways that the body uses to produce ATP needed for the continuation of muscle contractions.

The three main pathways that are involved in the production of ATP molecules depend on if muscle is undergoing an anaerobic or aerobic condition. TI fibers are involved with aerobic activity with large oxygen uptake by cellular respiration. TII muscle fibers are used in anaerobic conditions with fast, high intensity activity. During these conditions ATP is produced by the creatine phosphate pathway, or by fermentation (Mader & Windelspecht, 2014; Westerblad et al., 2010). ATP production in high intensity, anaerobic conditions have been researched throughly and even with the large amount of research it is still unclear the exact glycogen breakdown mechanisms at high rates (Westerblad et al., 2010; Katz et al., 2003).

In the creatine phosphate pathway there is regeneration of ATP by the breakdown of phosphocreatine (Westerblad et al., 2010). Research shows that this pathway will produce enough ATP for the first 2-7 seconds of an exercise, and why it can be used most in TII fibers (Westerblad et al., 2010). In this reaction, break down of phosphocreatine by creatine kinase will directly donate an extra phosphate group to an ADP molecule to form ATP (Westerblad et al., 2010). This pathway is the simplest and the fastest way for the muscle to produce ATP, and provides enough energy for shorter, more intense exercise like lifting weights.

Fermentation is the second pathway for ATP production in an anaerobic environment. During this process, a total of 2 ATP molecules are produced from the breakdown of glucose to lactate (Westerblad et al., 2010). The collection of lactate in muscles occurs mainly during heavy exercise when the ATP is consumed at large rates, and ultimately leads to the increase of acidity in the muscle because of the lactate production (Mader & Windelspecht, 2014). During glycolysis, glucose is broken down into pyruvate and NADH molecules. NADH is then oxidized, losing an H+ ion and together NADH and pyruvate are converted into lactate and NAD+ by the enzyme lactate dehydrogenase (Westerblad et al., 2010; Katz & Sahlin, 1988). H+ and lactate working in coordination with each other increases the acidity levels, which ends up being toxic to cells (Mader & Windelspecht, 2014). Excessive levels of lactic acid in a muscle can ultimately lead to pain and fatigue in the muscles (Fox, 2011).

Muscle Fatigue

Muscle fatigue can be described in many ways including the inability of a muscle to generate any continuing force, usually due to some type of exercise (Fox, 2011). It can also be defined, as the demand for ATP is higher at the rate at which it can actually be produced by the body. Ultimately, fatigue is often present during an exercise because there is some time of constant stimulation, applied to a target muscle or muscle groups, which results in a decline in the tension that the muscle can actually produce during contraction (McGinnins, 2013). All of the above definitions can be attributed to the three different pathways in muscle cell metabolism.

During a muscle contraction there is depolarization of the muscle cell when there is a rush of Na+ into the cell, and repolarization when there is a rush of K+ out. In exercises that are short with high intensity, current research shows that fatigue can be induced when there is a large amount of K+ molecules in the extracellular membrane. As the action potentials propagate down the transverse tubules, there also becomes an accumulation of K+ molecules in the narrow spaces where these tubules reside (Fox, 2014). When there is too much accumulation of K+, there becomes the reduced ability of action potentials to be created because there is an uneven balance within the membrane potentials (Edwards, 1981). Without any generation or propagation of action potentials about the sarcolemma, there will be a decrease in the amount of Ca+ released from the sarcoplasmic reticulum and there can be no initiation of muscle contraction within a muscle fiber (Edwards, 1981).

Studies conducted during early 1900's show that muscle fatigue is also caused by the collection of lactic acid in the fermentation pathway during exercise (Edwards, 1981). This has been a traditional interpretation of muscle physiology for centuries, but recent research has found alternative routes for muscle fatigue depending on the type of exercise being performed. One theory is that the muscle can start to fatigue when there is an increase in phosphate concentrations in the cytoplasm of the cell. This is due to the breakdown of phosphocreatine into phosphate and creatine molecules. This in return will reduce the force that is being produced by cross bridges during muscle contraction (Fox, 2104). Another current theory of muscle fatigue is the accumulation of ADP within the muscle cell, which is thought to slow down the velocity during muscle shortening. Lastly, there also had been suggestions that muscle fatigue can be contributed to the limited amount of glycogen within the body. Researchers are not completely sure on the mechanism to why this is happening. Although more research is needed, they believe limited glycogen amounts are directly related to a decrease in the amount of Ca+ released from the sarcoplasmic reticulum (Fox, 2014).

The above reasons are all considered factors as to which targeted muscles can fatigue during an exercise, or also known as peripheral fatigue (Fox, 2014; Edwards, 1981). During peripheral fatigue, there is actual fatigue within the muscles themselves because of some kind of disruption in force produced. Humans can also experience central fatigue, which is caused by the central nervous system rather than by the actual fatigue in the muscle by some factors related to metabolic pathways (McGinnins, 2013). Factors that contribute to central fatigue would include the limited amounts of full functioning motor units in the human body, or limited amounts of motor unit firing frequency within a muscle usually due to motivational factors (Edwards, 1981). Usually in situations where central fatigue takes over, the muscle had not completely reached full fatigue potential (Fox, 2014). As mentioned above, fatigue is highly related to the type of exercise that is being performed by athletes. Fatigue and the rate of tension within a muscle contraction is directly related to the type of muscle fibers affected (McGinnins, 2013).

Fatigue in the shoulder complex is important to identify in sports such as swimming, baseball, football, tennis and others that involve overhead arm rotations. Fatigue in these overhead athletes is thought to be a neuromuscular issue that often leads to shoulder pathology

(Szucs et al., 2009; Sood et al., 2007; Bowman et al., 2006; Ludewig & Cook 2000).
With a type of shoulder pathology, there usually comes some biomechanical change in movement of the joint in association with the pain that presents with normal movement, and may be a result of repetitive overhead movement patterns (e.g., swimming) (Szucs et al., 2009; De Morais et al., 2008; Cools et al., 2007).

Muscle Fiber Types

Motor units are usually broken down into different groups based on two important qualities: contractile speed and fatigue characteristics (Scott et al., 2001). Human skeletal muscle differs in fiber-type composition which can be broken down into two different types including: Type I slow twitch and Type II fast twitch fibers, which are categorized by their speeds of shortening (Scott et al., 2001). Fibers are recruited differently depending on the type of exercise an athlete is performing. TI fibers are more efficient at using oxygen thus being able to produce more ATP for continuous exercise. They usually appear red when distinguishing types because of the high amounts of myoglobin and large capillary content, which allows the ability for larger oxidative capacities (Scott et al., 2001). TI fibers also usually contain more mitochondria, which is where cellular respiration is taking place and ATP is produced for muscle contraction. These fibers fire at slow rates, and are recruited during endurance exercises to provide the ability for continuous extended muscle contractions over longer periods. This in return leads to slower fatigue rates in athletes.

Type II muscle fibers are recruited during faster, shorter movements that involve short bursts of energy and normally appear white due to lower myoglobin and capillary content. These fibers fire more rapidly and are able to generate more force during exercise, but in return tend to fatigue quicker. TII fibers are broken down into two sub-types: Type IIA (TIIA) and Type IIX

(TIIX) where TIIA is classified as a combination of TI and TII. TIIX have the highest rates of contraction amongst all fiber types and thus higher rates of fatigue during performance. One researcher suggests that it is possible that areas with higher amounts of TIIX fibers may be more easily affected by fatigue in movements and exercises that involved higher rates of repetitive work (Lindman et al., 1991).

Muscle fiber type composition is largely determined by ones genetics, but can also be changed by exercise. Fibers can adapt to changing demands by changing size, or as in exercise, can actually change in composition (Scott et al., 2001). It is more common to see conversions of fiber types from TII to TI from results of high endurance training, but fiber transitions have also been seen from TI to TII in high-intensity resistance training (Scott et al., 2001; Kraemer et al., 1995).

Fiber Type Composition in Upper Extremity Muscles

Determination of muscle fiber recruitment during muscle contraction can be beneficial when trying to research fatigue patterns in swimmers and other athletes. Based on the muscles used in different phases of the swimming stroke, researchers can help determine which muscles would expect to fatigue faster in overhead athletes. Past research shows that muscle fiber type in humans is greatly related to genetics (Fox, 2014). Although genetics has a large role in muscle fiber type composition, many studies have been conducted to evaluate these numbers in muscles of the upper body in humans.

In 1991, Lindman et al. performed a study on the fiber type composition in the human female trapezius muscle. Fibers in each section of this muscle are recruited differently depending on the type of action being performed. The upper trapezius is used during upper extremity loading and when trying to elevate the shoulder. The middle and the lower sections of the trapezius muscle are used more frequently during retraction and rotation of the scapula (Lindman et al., 1991). During this study, Lindman and colleagues analyzed sections of the right trapezius muscle of 4 female cadavers with the mean age of 22. They found multiple fiber type patterns between each of the muscle sections. This study shows that the upper trapezius muscle has more TI muscle fibers than the middle trapezius muscle. This study also reported that there are more TI fibers in the lower trapezius section, than there are TII fibers. Overall, the trapezius muscle has more TI fibers than TII fibers with the lower third section of the upper trapezius, middle and lower trapezius being composed mostly of these fibers. Although this muscle is mostly composed of TI as a whole, they found a larger abundance of TIIX fibers in the superior section of the upper trapezius muscle than in any other section (Lindman et al., 1991).

In a study performed by Mannion et al. (1997), muscle fiber typing was conducted in the lumbar erector spinae muscle (ES). In this study, left sided ES samples were taken from 14 healthy females without any lower back pain from areas around the 3rd lumbar vertebrae. They found that the prominent fiber type found in this muscle was TI muscle fibers, which made up about 70% of the total fibers found in samples. Another finding in this experiment was that if the subject did not have more TI fibers than TII fibers than the actual TI muscle fibers themselves were larger in size (Mannion et al., 1997). The findings in this seem logical due to the ES' role as a postural muscle in the human body.

Sirnivasan et al. (2007) performed a pilot study where 14 muscle fiber type compositions among the glenohumeral joint were sampled in 4 male cadavers. In this study, they found averages of TI and TII muscle fiber types in 2 muscles specifically used in swimming including the posterior deltoid and the infraspinatus. This pilot study concluded that the infraspinatus was composed around half of TI fibers, while the posterior deltoid muscle was composed of 56% of

TI fibers. Overall muscles in this region had higher percentages of TI fibers than TII fibers, but the posterior deltoid had the highest average of TI muscles when comparing amongst each other (Srinivasan et al., 2007).

There have been few studies performed on the fiber type composition of the serratus anterior (SA) in humans to be able to report which fiber types are normally present. One study performed by Potluri et al., (2006) looked at the serratus anterior muscle fiber type composition in rats. This study concluded that the SA was composed of a large number of TIIX muscle fibers, taking up 77-87% of fiber types in the muscle. Potluri et al., suggest that is this is similar to the SA in humans, then this could be considered a faster fatiguing muscle during exercise (Szucs et al. 2009; Potluri et al., 2006).

Electromyography

There are two different techniques that are involved in EMG testing. Needle EMG (nEMG) is often used in analyzation of deeper muscles. Surface electromyography (sEMG) is another common technique used to measure surface muscles' activation in the upper extremity and upper thoracic region (Lomax et al., 2015; Martins et al., 2008). EMG measures the muscle demand by reading electrical signals given off by action potentials during contractions created by motor units within a given exercise (Xiao et al., 2014, Martins et al., 2008). This technique is frequently used to measure fatigue rates in muscles by measuring factors like median frequency (Lomax et al., 2015; De Luca, 1997). Using sEMG to measure muscle activity is important because changes in sEMG readings can directly correlate with the functional state of the muscles being tested, and can also analyze the musculature demand that is used to perform different exercises (Zhou et al., 2011; Martins et al., 2008). Interpreting physiological signals as ones demonstrated during EMG testing is critical for studies involved with sport science. Results are used for improvements in strength training programs for athletes, and for bettering different sport rehabilitation designs (Konrad, 2005).

EMG studies of swimmers started around 50 years ago, and since have helped elucidate muscle function in the swimming stroke (Martins et al., 2008). More recent studies showing new EMG testing results on the upper extremity muscle activation in swimmers have found a large number of upper body muscles that fatigue during maximal freestyle swimming (Lomax et al., 2015; Ikuta et al., 2012; Stirn et al., 2011; Aujouannet et al., 2006). Research shows that the freestyle stroke is frequently a source of shoulder impingement issues in swimmers, and as mentioned earlier one of the most frequently practiced strokes during a swimming season (Nuber et al., 1986). Even with large amounts of research, there are still few sEMG studies have been directly related to muscles that are involved with the recovery and glide reach phase of the freestyle stroke including the infraspinatus, serratus anterior, middle trapezius, upper trapezius, and the posterior deltoid in collegiate swimmers (Heinlein & Cosgarea, 2010). Collegiate swimmers are an important group to consider when evaluating the swimming population due to large amounts of time in the water by these athletes on a daily basis. Using Division 1 athletes as subjects for testing can lead to more accurate results when evaluating muscle fatigue patterns in swimming. Overall identifying these patterns in upper body muscles used by swimmers can be crucial to the development of better rehabilitation programs at this level. Researchers still do not fully understood what controls of the shoulder and upper extremity movement, but needs to be evaluated because it is important to the overall health of the shoulder (Szucs et al., 2009).

One of the most frequent types of exercises that are performed during sEMG studies is testing isometric contraction. During an isometric contraction there is no change in the joint angle that is being tested, and there is no change in the length of the muscle (McGinnis, 2013).

Past studies show that EMG data gathered from these types of exercises have produced more reliable results than any studies that have been performed with a dynamic exercise (Fauth et al., 2010).

There have been few EMG studies done focusing on the SA muscle, but subjects tested were not swimming athletes. A study performed by Szucs et al. (2008) tested fatigue rates in three muscles including the SA, the UT and the LT using EMG on 28 asymptomatic shoulder pain female subjects, with female mean age of 25. During this study subjects performed a task designed to fatigue the SA by doing a push up exercise until subjects on their own decided they were to the point of fatigue. Conclusions of this study reported that with the fatigue of the SA, there was an increase of activation rates in the UT. This study proposed that with these results, it suggests that the UT may be less susceptible to fatigue and that the muscle may actually be recruited more to compensate for fatigue of surrounding shoulder muscles (Szucs et al. 2008).

Martins et al. (2008) studied similar muscles using sEMG. During this study, 12 male subjects with the mean age of 22 were asked to perform a series of isometric exercises to look at relationships in the fatigue patterns between the SA and the UT. This study reported similar results as Szucs and colleagues, showing that there is a decrease in SA activity in most of the exercises that were performed. They also suggest that this could be due to the fact that there is higher muscle recruitment of other shoulder muscles. They concluded that there was limitations in this study due to the fact that they only studied the UT and the SA muscles. They suggest that further testing should be done with sEMG looking at more surrounding shoulder muscles (Martins et al., 2008).

One study performed by Lomax et al. (2015) did test a population of 14 trained swimmers looking for the relationship between dual role breathing and upper body muscles in the freestyle stroke. During this study they used sEMG to test fatigue rates in three muscles including the SA, the pectoralis major and the latissimus dorsi. They measured muscle activity rates before and after a swimming activity, and they did find that fatigue was shown in all three muscles. They also conclude that the SA is highly susceptible to stroke changes in swimmers (Lomax et al., 2015).

Median Frequency

Frequency is an important component in EMG testing because it shows the firing rate of action potentials over a period of time. Commonly in EMG studies, time domain is used as a variable when doing data analysis where it shows how a signal changes over time. Analysis parameters in EMG studies analyzing fatigue use total power spectrum to obtain accurate information (Thongpanja et al., 2013). When analyzing EMG readings, fatigue is present when there is a shift to lower frequency outputs in the spectrum (Winter, 1990). When taking these facts into consideration, it is important to understand different types of muscle fiber types that are being tested. Fibers that are categorized as fast-twitch and rely on anaerobic respiration will decrease in their activity, or could completely stop firing before fibers that are categorized as slow-twitch. Range frequencies are different depending on the fiber type that it being fired. TI or slow twitch fibers’ frequency range between 70-125Hz, while TII or fast twitch fibers’ range between 126-250Hz (De Luca, 1983).

Past studies use median frequency (MDF) as a common measurement of fatigue in further data analysis. MDF can be described as a frequency value that is obtained from the EMG total power spectrum, where the power spectrum is divided in half into two regions showing equal total power (Thongpanja et al., 2013). As mentioned above, fatigue is thought to be present when there is a shift to lower frequency outputs in the power spectrum. MDF analysis can be used to estimate the magnitude of that shift (Winter, 1990). Using median frequency to determine fatigue rates can be more accurate because this value is not easily affected to extremes in range of the power spectrum (Merletti et al., 1990). The power spectrum of an EMG signal shows the frequency power dispersal on the y-axis and the frequency band on the x-axis (Konrad, 2005). The decrease in the conduction velocity of action potentials is directly proportional to the decrease in duration in which they contract. This ultimately causes a decrease in the median frequency (MDF). This decrease can serve as an index of fatigue in EMG signals (Merletti et al., 1990).

Researchers may further compute the slope values of the MDF' that are analyzed. Modern biomechanical technology can compute these slope vales by looking at the frequency values over a time domain, as mentioned above. When there is a negative value in the slope of the MDF computed, that is representing that there is fatigue present in the muscle over a certain period of time. This goes the same way for if there is a no slope, or a positive slope value for MDF, there is no fatigue present in the EMG reading for that given study. The more negative a slope value, the more fatigue that is being shown in an EMG reading.

Summary

Little research has specifically focused on better rehabilitation treatments for elite Division 1 swimming athletes. It is important to start investigating the causes of these issues, and muscles that are also involved in the overhead movement of the swimming stroke. The shoulder is one of the most unstable joints in the body, and the precise control of movement of the shoulder during use can be a serious component to the over health of the shoulder region. Although it is highly important for overall health of the shoulder, control is not fully understood by researchers (Szucs et al., 2009). Understanding fatigue rates in overused muscles can help collegiate programs develop better pre-workout exercise routines to strengthen these muscles to hopefully reduce muscle fatigue rates. One technique that can be used to test muscle activity and rates of fatigue is through electromyography (EMG). By using EMG, it is expected to see that if the subject is a swimmer, then they will have fatigue rates that are significantly slower than non-swimmer subjects. It is also expected to see that the swimmers will be able to perform exercises for longer periods of time than non-swimmers due to the hours of exercise they perform on a daily basis. This study will also take into account tricep lean mass into account of overall shoulder strength, where the more tricep lean mass someone has the longer they should be able to perform an exercise. Another important hypothesis that this study will address, is if a simple shoulder questionnaire used by Brophy et al. (2015) will be able to dictate overall shoulder endurance strength in people.

What will be taken from this study, is being able to distinguish which muscles fatigue at faster rates in swimmers, and be able to use these results and conclusions from past studies to create a rehabilitation program to strengthen muscles. It is thought that there are certain muscles in the shoulder complex that are compensating for the fatigue rates in surrounding shoulder muscles. If there are certain muscles that are showing higher rates of fatigue in median frequency values, than these muscles need to be focused on more in strength programs in athletes.

CHAPTER 2

MATERIALS AND METHODS

Subject Demographics

This study took place at Marshall University's Physical Therapy School in Huntington, WV. Before the subjects were recruited, proper Institutional Review Board (IRB) approval was obtained (IRB1 #00002205 and IRB2 #00003206). Female subjects were recruited in various ways, including flyers around Marshall University campus and actively recruiting subjects from various Biology classes at the university. A total of 11 subjects labeled as swimmers were recruited from a Division 1 collegiate woman's swimming team, and 20 non-swimmers participated in the study. Before subjects were approved as qualified for participation they had to meet the following criteria: no shoulder pain other than soreness from working out in the past 6 months, or have had a shoulder surgery in the past year. When recruiting subjects for participation, females were selected based on subject demographics. These athletes range between the ages of 18-23 and weight between 130-180 pounds. The mean age of the 31 test subjects was 19.90±1.53 SD (Swimmers = 19.72±0.90 SD, Non-swimmers = 20.25±1.68 SD). No parameters were set when recruiting the non-swimmer group in regards to how many hours a week they exercised.

Subject Preparation

The subjects were given a brief overview of what the study would involve, and time to fill out multiple packets including: an informed consent page, Health Insurance Portability and Accountability Act (HIPAA), a past medical history questionnaire, and a shoulder activity scale form. Brophy et al. (2005) used this shoulder activity scale for research involving measurements of shoulder activity level in patients to help predict outcome of shoulder disorders (Brophy et al., 2005). Another question that was asked on the questionnaire and was taken into consideration was if subjects played a sport in the past, and if yes they were asked to explain which kind. Subjects were then asked to change into a gown to wear during the testing and were asked to remove any clothing including bras in order to make proper electrode placements and eliminate interference. The subject's height, weight, and arm length of their dominant arm was recorded on the appropriate data sheet. The subjects arm length was measured from the tip of the acromion to the radial styloid process. Torque was standardized for each subject by calculating 20Nm on the shoulder during each exercise performed. This was obtained by using data collected from weight and arm length of each subject. Past research in biomechanics has estimated the weight of an average woman's arm by using averages of cadaver arm weight (Chaffin et al., 1999). To obtain 20Nm of torque lighter subjects held 3.5 pounds, and heavier subjects held three pound hand-held weights at each angle. This weight was selected due to the primary researcher's knowledge with physical therapy rehabilitation, where a proper weight was used that would fatigue subjects between 30sec-120sec (Dr. Neil Evans, pers. comm.). Weight was added to the subjects' load in order to use this as the determination of fatigue rates between both subject groups.

The circumference of the upper portion of the testing arm was also measured to in order to calculate the total area of tricep lean mass in each subject. The equation to calculate the area was taken from McArdle et al. (2014). A skin fold measurement was taken with calipers on the same arm testing arm and was also used in the calculation. This technique was added into the experiment in order to find arguments to why subjects would be able to perform an exercise longer than another.

Electromyography Setup

Surface electromyography (sEMG) was used to test seven different posterior muscles involved in upper extremity movement on the subject's dominant side following Uhl et al. (2003). Muscles tested include: posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), infraspinatus (INFRA), serratus anterior (SA), and the lumbar erector spinae (ES). The electrode placement measurements for the seven muscles being tested were obtained from the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM), excluding the placements for the INFRA and the LES. The PD electrodes were placed 3cm inferior to the angle of the acromion process; the UT electrodes where placed between the midpoint of the C7 vertebrae and the acromion process; the MT electrodes were placed between the midpoint of the T3 spinous process and the medial border of the scapula; the LT electrodes were placed 2/3 distance from the superior medial angle of the scapula to the T8 spinous process; INF electrodes were placed 2 cm from the medial border midway between the spine of the scapula and the inferior angle of the scapula (Uhl et al., 2003). The SA electrodes were placed anterior to the latissimus dorsi muscles, and between the 7/8 rib; and the LES electrodes were 4cm laterally to the third lumbar and spinous process (Figure 2.1) (Lühring, et al., 2015).

A measuring tape was used in order to properly place the electrodes in above requirements, and the areas were prepped before electrode placement (Uhl et al., 2003). The areas were brushed with sandpaper and then cleaned with alcohol pads to ensure for the least amount of impedance during the study (Xiao et al., 2014). The EMG program that was used during the experiment was NORAXON Desktop Direct Transmission System (DTS), with 7 wireless sensors and associated electrodes. Bipolar surface electrodes were placed 20mm inter-electrode distance, in parallel position to the muscle fibers of the muscle being tested. The NORAXON sensors were placed directly parallel to the electrodes and the wires were connected to the associated electrode. To ensure that the combined electrode and EMG sensor would stay in position during the testing, a piece of tape was placed over the area that allowed for movement of the extremities. After the placement of the electrodes, muscles were tested to ensure for proper placement by watching recordings on the computer screen connected to the wireless system.

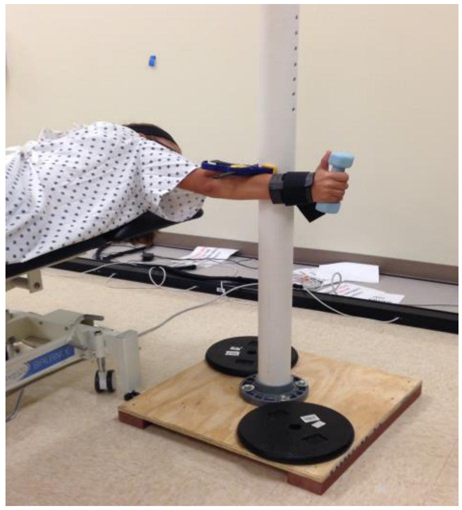
Before the first position, subjects were asked to participate in a 5 minute-warm up period on the upper body ergometer to improve performance during the testing. The pace at which the subjects performed the warm-up was at their own discretion, which was decided by the primary researcher conducting this study. When the subject was finished with warm-up, the testing process was explained to them in detail. They were instructed to lay on their stomach on the examination table that was set up close to the computer and NORAXON EMG recording program, with their dominant arm able to hang off the side. There was a pole sitting next to the table that had a clamp attached, which acted as a goal for each of the subjects to reach during the testing period. Depending on the subjects testing number, their two tests consisted of holding their arm with the measured weight against the clamp at horizontal abduction of the shoulder joint at 90° ("T"), or at horizontal abduction of the shoulder joint at 135° ("Y"). Subjects started at different angles depending on their testing number to eliminate the possibility of one angle affecting the subject before the other angle was tested. A standard goniometer was used to obtain these angles before testing (Uhl et al., 2003). Before the subjects started the first test, they were assessed to see if they could feel the clamp with their arm and then instructed to keep their thumb pointed up and looking at the weight the entire time testing was taking place. The subjects were asked not to press into the pole, but to push up into the clamp to ensure that they were not resting their arm against it. A camera was set up in the front of the testing table, which allowed for review of each of the subjects testing sessions after completion during data analysis.

When the subject was measured into the proper angle, they were put into testing position with the weight in hand. Before the timer started the subjects testing arm was held in proper position by a researcher and the subject was asked to try and completely relax, which was observed based on the EMG readings on the computer screen. When the subject was relaxed, the stopwatch was started and the arm was released to begin the testing process. The subject held the appropriate weight until failure. Failure was identified as not being able to hold the wrist against the clamp, major body position change, or when the subject lowered their arm at their own decision. The researcher that was in charge of the EMG computer program was also the one starting the handheld timer to ensure accuracy during testing. During the testing time the research team supported the subject verbally as a way to encourage the subject to give full effort. When the subject finished the first testing angle, the weights were removed around the wrist and they were asked to sit for 15 minutes without any upper extremity movement (Lomax et al., 2015; Enoka et al., 1989). After 15 minutes, the subjects were placed in the second testing position, and the same procedures were followed as mentioned above.

After the second test was complete, the sensors and electrodes were removed from the subject and the areas were cleaned properly with alcohol. Subjects were given copies of the signed paperwork to take home to ensure contact information if they sustained any problems after they left the testing site. The subjects only participated in the research once, and only one trial from each subject was obtained for this study.

After completion of initial subject testing, slopes of median frequency values from each muscle were obtained at each angle. This was done by using the video analysis data from the EMG program, and obtaining better start and end time to fatigue during subject testing. When these time periods were selected, they were entered into the program analyzer which was able to

Figure 2. An example the bipolar sEMG electrodes in proper placement before testing. © 2016, Tiffany Aeling

A. 

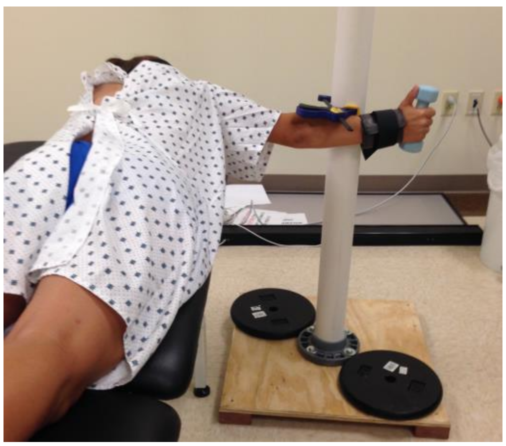
B.  C. 

Figure 3. Experiment set up with a participating subject. A. Demonstrates the pole and clamp combination used during the experiment. B. Subject with proper angle placement at 90°. C. Subject with proper angle placement at 135°. © 2016, Tiffany Aeling

compute slope values from each subject. Before any data were evaluated, 2 outliers were taken out of the data analysis due to significantly smaller area of tricep lean mass compared to the rest of the subjects. These outliers were taken out of all statistical tests performed during data analysis.

Statistical Experimental Design

To test hypothesis 1, that shoulder muscles will fatigue during a posterior shoulder endurance test, a two tailed *t*-test will be run on the slope of the median frequencies using JUMP Pro 11 statistical software program. Signs of fatigue will be identified by analyzing the upper and lower confidence intervals that are obtained from the t-test analysis. Confidence intervals that include numbers less than 0 from the median frequency slope values, show a positive fatigue pattern, while confidence intervals that result in numbers 0 and greater will show no fatigue pattern.

To test hypothesis 2, that if there are signs of muscle fatigue non-swimmers will have higher fatigue rates in muscles than swimmers, a One-Way ANOVA test will be run using the same statistical software program. P-values from the slope values of median frequency of each muscle at each angle between the two groups will be taken from the initial *t*-test, in order to identify significant differences. P-values that are <0.05 will show statistical differences between the two groups tested. In order to assume equal variances between the groups while running a One-Way ANOVA, a Welch's t-test will be run before to compare p-values of the Welch's test with the p-values from the ANOVA testing.

Hypothesis 3, that because swimmers use their arms more than non-swimmers, they will be able to hold an isometric exercise longer non-swimmers, a two tailed t-test will be run in order to obtain mean values for the total time to fatigue. Upper and lower confidence intervals in each group will also be obtained from this data. A One-Way ANOVA will be run in order to see if there are differences between the groups for total time to fatigue at the angles. Again, p-values obtained from initial *t*-test that are <0.05 will show statistical differences between the overall time to fatigue between the two groups.

To test hypothesis 4, that the amount of tricep lean mass in an individual has an effect on the duration of muscle activity, will be analyzed by running a bivariate analysis using the above program. Regression lines comparing the total time to fatigue to the area of tricep lean mass at each angle will be used to compare data. R^2 values will be obtained from the results, and a One-Way ANOVA will be run in order to obtain p-values for each angles tested. P-values that are <0.05 will show statistical differences between the two groups tested.

To test hypothesis 5, that a shoulder activity questionnaire can accurately aid in evaluating the strength of an individual's shoulder endurance, a Wilcoxon's test on the data obtained from the shoulder activity questionnaire totals that were given to the subjects at the beginning of the testing. Subjects that have higher scores on the questionnaire are said to be using their shoulders more on a daily basis than subjects that have lower scores. This in return could lead to further reasons why a subject might have muscles that are fatiguing at slower rates, and have muscles that are showing less fatigue patters between the two groups. Subject's scores will be computed using a numbering system used in research done by Brophy et al. (2005). The highest score one subject could get was 20/20, with the lowest being a 0/20. The means and standard deviations will be collected from each group after calculating the total scores. The Wilcoxon's test will use the means from the two groups, and evaluate if there are differences between the mean scores obtained during questions. This non-parametric statistical test had to be used due to the fact that the means of the scores between two groups were taken, and it is assumed that this data is ordinal, which calls for this type of statistical testing.

CHAPTER 3

RESULTS

Slope of Median Frequency Results

Hypothesis 1 was to test if there were signs of muscle fatigue during an isometric exercise. A two-tailed *t*-test was run on the data and the mean values, lower, upper confidence intervals (CI), and p-values for the SMDF were obtained. Data from this test is represented in Table 1. Upper CIs that are less than zero are statistically significant due to the fact that a negative slope value shows positive fatigue results over the duration of the exercise performed. An upper CI with a slope value 0 or greater represents no fatigue patterns during testing (Table 1). All muscles did show signs of fatigue in both groups excluding the SA and the ES muscles which will not be further analyzed in the statistical analysis.

Because results from the *t*-test did show signs of fatigue during testing in both groups, a One-Way ANOVA on the slopes of the median frequency (SMDF) values at each angle was conducted to see if there were differences between the two groups tested. The ANOVA gave three significant results with p-values that were <0.05. These results are represented in Table 2. The first value that showed significance from the *t*-test was the PD at 135º with a p-value of 0.0221. Figure 4 represents significant differences between fatigue rates in non-swimmers and swimmers during this testing angle. The non-swimmer group had a mean value of -0.5279 Hz, with the lower 95% CI of -0.6295 Hz, and the upper 95% CI of -0.4263 Hz, while the swimmer group had a mean of -0.3326, with a lower CI of -0.4626 Hz and an upper CI of -0.2027 Hz (Table 1). The second value that showed significance was UT at 135º with a p-value of 0.0317. Figure 5 represents significance between both groups. The mean SMDF for non-swimmers in the UT at this angle was -0.5730 Hz with a lower CI of -0.6752 Hz and an upper CI of -0.4708 Hz.

Table 1. Two- tailed t-test results of median frequency slope values at 90° and 135° in each muscle tested. * represents statistically significant results where the upper and lower confidence intervals do not include zero. Upper confidence interval values that do include zero show muscles that were not significantly fatiguing during testing sessions.

Muscle	90°						135°					
	Non-Swimmers			Swimmers			Non-Swimmers			Swimmers		
	Mean	95% Lower CI	95% Upper CI	**Mean**	95% Lower CI	95% Upper CI	**Mean**	95% Lower CI	95% Upper CI	**Mean**	95% Lower CI	95% Upper CI
PD	**-0.3890**	-0.5355*	-0.2426*	**-0.2998**	-0.4871*	-0.1124*	**-0.5279**	-0.6295*	-0.4263*	**-0.3326**	-0.4626*	-0.2027
UT	**-0.4406**	-0.5410*	-0.3402*	**-0.3731**	-0.5015*	-0.2447*	**-0.5730**	-0.6752*	-0.4708*	**-0.3898**	-0.5205*	-0.2591*
MT	**-0.4487**	-0.5501*	-0.3472*	**-0.3169**	-0.4466*	-0.1871*	**-0.4548**	-0.5485*	-0.3611*	**-0.3226**	-0.4424*	-0.2027*
LT	**-0.3179**	-0.3926*	-0.2433*	**-0.1668**	-0.2623*	-0.0713*	**-0.3817**	-0.4567*	-0.3066*	**-0.3483**	-0.4443*	-0.2524*
INF	**-0.5876**	-0.7625*	-0.4127*	**-0.4470**	-0.6707*	-0.2233*	**-0.6786**	-0.9085*	-0.4488*	**-0.3320**	-0.6260*	-0.0379*
SA	**-0.1887**	-0.4234	0.0460	**-0.2750**	-0.5753	0.0253	**-0.0447**	-0.2497	0.1603	**-0.1692**	-0.4314	0.0930
ES	**-0.0338**	-0.1408	0.0732	**-0.0675**	-0.2043	0.6930	**-0.0663**	-0.1819	0.0493	**-0.0401**	-0.1880	0.1078

Table 2. p-values of each muscle at both angles measured during subject testing. * represents data that is significant with p > 0.05, only in the muscles that showed signs of fatigue.

Muscle	90°	135°
	P-value	P-value
PD	0.4476	0.0221 *
UT	0.4031	0.0317 *
MT	0.1121	0.0857
LT	0.0164 *	0.5794
INF	0.3185	0.0674

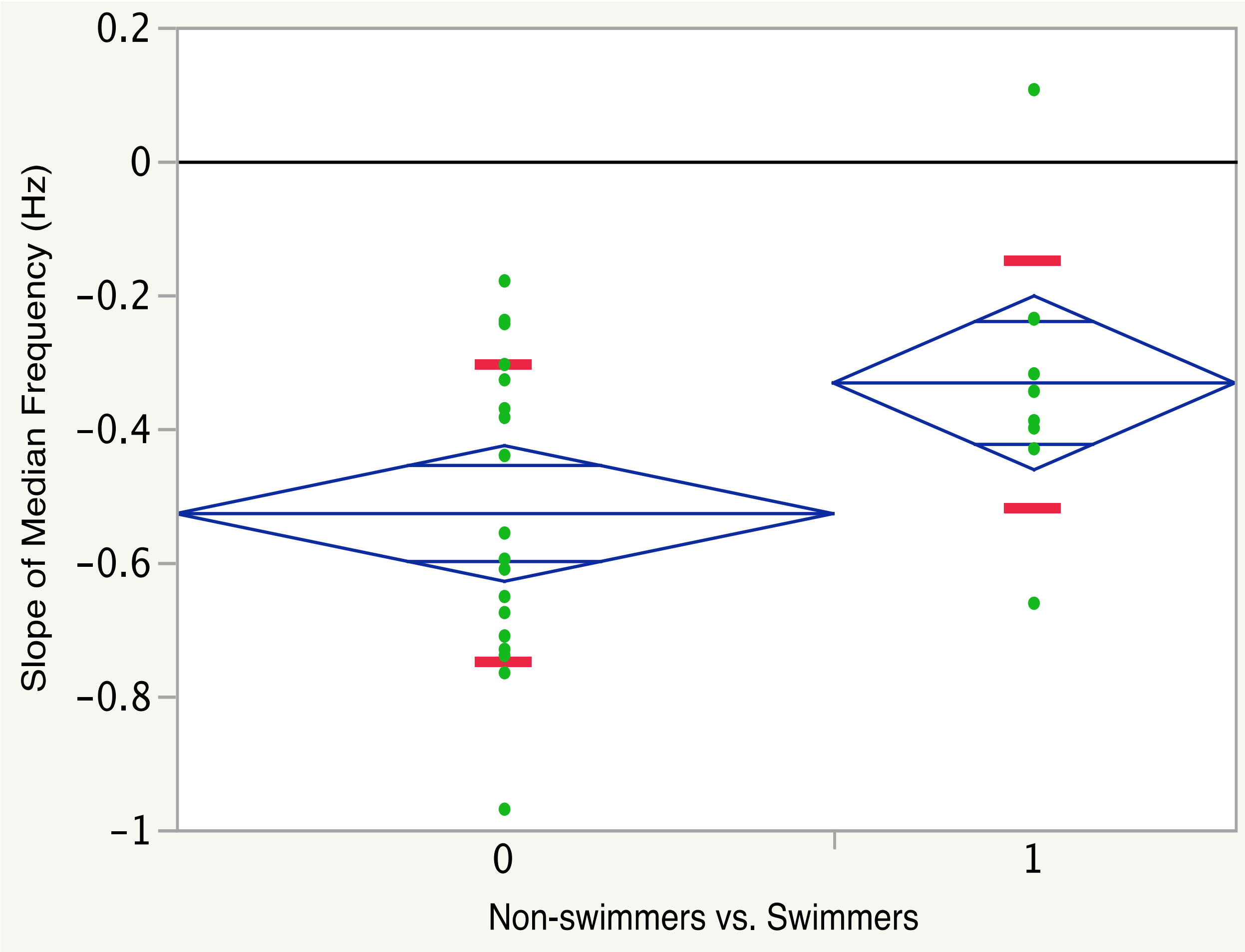


Figure 4. Graphical representation for slope values of the median frequency in the posterior deltoid muscle at 135°. P-value between the two groups is 0.0221. Blue- diamond shape represents confidence intervals of each group. Center line in diamond represents group means. Vertical span represents 95% confidence intervals for the mean of each group. Top point of diamond is upper 95%, bottom point of diamond is lower 95%. Lines above and below group mean are overlap marks that allow easier view for signs of significance. Horizontal span of diamond presents sample size tested. Green circles represent each subject tested. Red lines represent standard deviations. 0= Non-swimmers, 1= Swimmers.

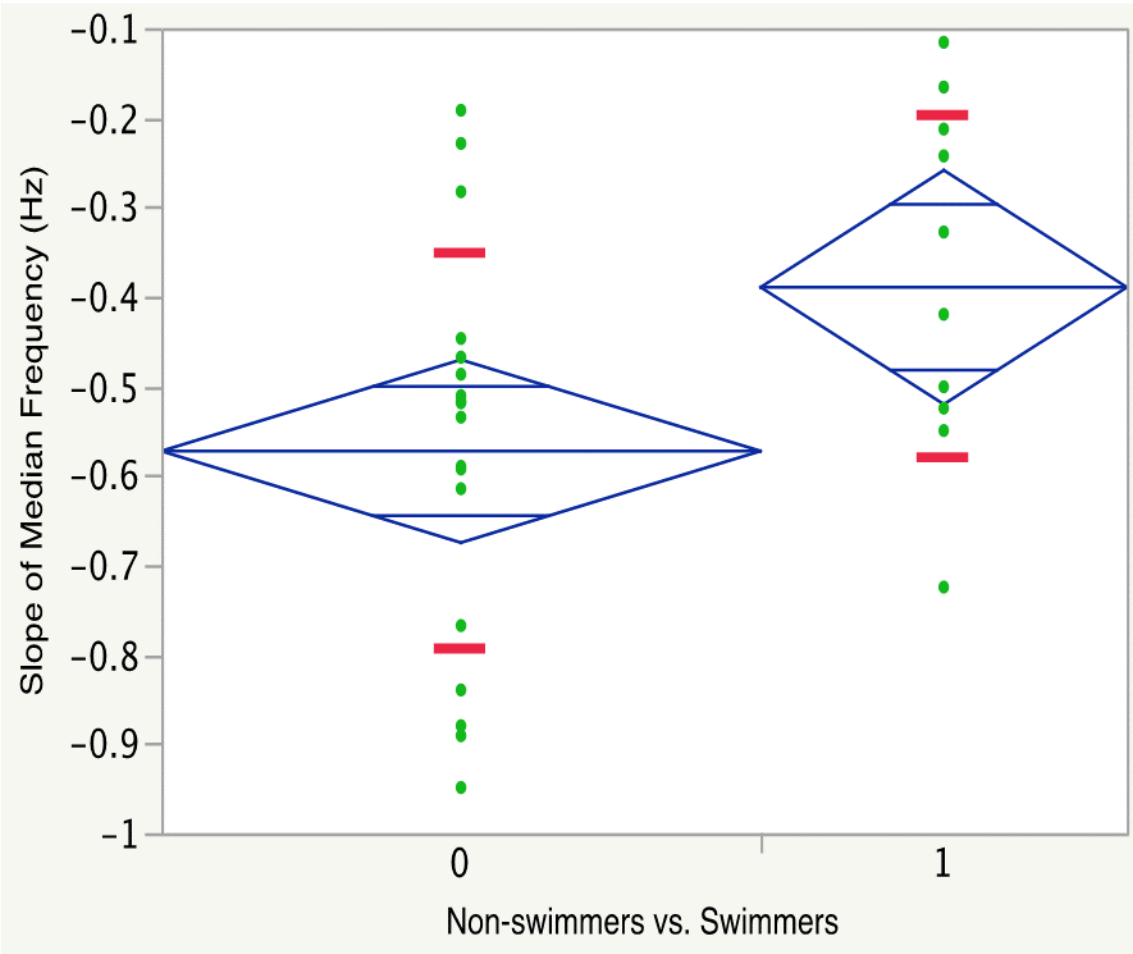


Figure 5. Graphical representation for slope values of the median frequency in the upper trapezius muscle at 135. P-value between the two groups 0.0317. Blue-diamond shape represents confidence intervals of each group. Center line in diamond represents group means. Vertical span represents 95% confidence intervals for the mean of each group. Top point of diamond is upper 95%, bottom point of diamond is lower 95%. Lines above and below group mean are overlap marks that allow easier view for signs of significance. Horizontal span of diamond presents sample size tested. Green circles represent each subject tested. Red lines represent standard deviations. 0= Non-swimmers, 1= Swimmers.

The mean SMDF for the swimmers was -0.3898 Hz with a lower CI of -0.5205 Hz and an upper CI of -0.2591 Hz (Table 1).

The last muscle that showed significance between the two groups was the LT at 90º with a p-value of 0.0164 which is represented in Figure 6. The mean SMDF for non-swimmers was -0.3179 Hz, with a lower CI of -0.3926 Hz and an upper CI of -0.2433 Hz. The mean SMDF for the swimmer group at this angle was -0.1668 Hz, with a lower CI of -0.2623 Hz and an upper CI of -0.0713 Hz (Table 1).

Total Time to Fatigue

Hypothesis 2 was conducted to evaluate overall time to fatigue during both exercises performed. The first test analyzed was a two-tailed *t*-test that gave the mean values, lower, upper confidence intervals and p-values for the total time each subject was able to perform the exercise until fatigue and is represented in Table 3.

After showing there were signs of fatigue in both groups, a One-Way ANOVA was also run on the data collected to evaluate if there were differences between groups at each angle tested. Significant differences are shown on Table 4, that show p-values <0.05 from initial *t*-test. Figure 7 shows significant differences between groups at 90º, with swimmers holding the weight at this angle longer than non-swimmers with a p-value of <0.0001. The mean time held for non-swimmers at 90º was 55.121 seconds, with a lower CI of 52.660 sec and an upper CI of 57.582 sec. The mean time held for swimmers at this angle was 64.209 sec, with a lower CI of 61.061 and an upper CI of 67.357 sec (Table 3).

Figure 8 represents that there was no significance found at 135º between the two groups with a p-value of 0.1864 (Figure 8; Table 4). The mean time held was 48.364 sec and 51.018 sec for non-swimmers and swimmers, respectively (Table 3).

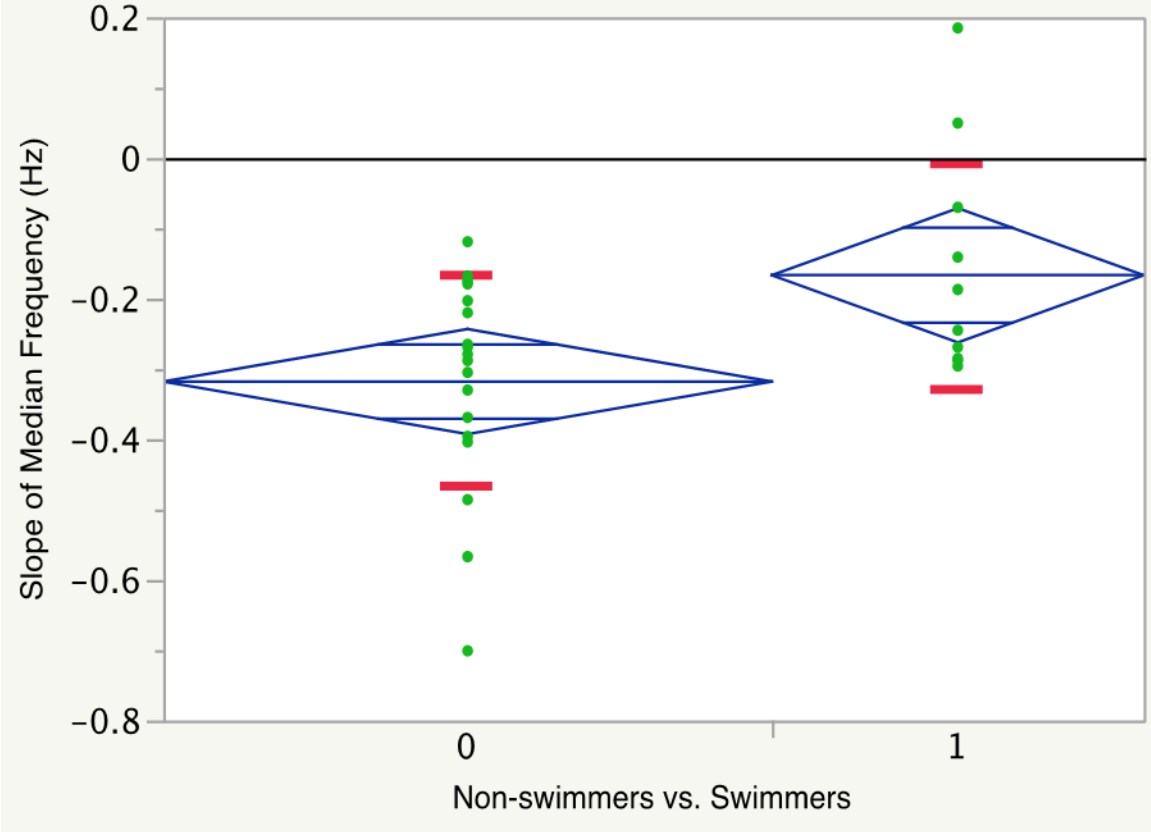


Figure 6. Graphical representation for slope values of the median frequency in the lower trapezius muscle at 90°. P-value between the two groups 0.0164. Blue-diamond shape represents confidence intervals of each group. Center line in diamond represents group means. Vertical span represents 95% confidence intervals for the mean of each group. Top point of diamond is upper 95%, bottom point of diamond is lower 95%. Lines above and below group mean are overlap marks that allow easier view for signs of significance. Horizontal span of diamond presents sample size tested. Green circles represent each subject tested. Red lines represent standard deviations. 0= Non-swimmers, 1= Swimmers.

Table 3. Two-tailed t-test results comparing total time groups held weight until point of fatigue at 90° and 135°.

Subject	90°			135°		
	Mean	95% Lower CI	95% Upper CI	**Mean**	95% Lower CI	95% Upper CI
Non-Swimmer	**55.121**	52.660	57.582	**48.364**	45.934	50.795
Swimmer	**64.209**	61.061	67.357	**51.018**	47.909	54.127

Table 4. P-values of total time held to fatigue at both angles measured during subject testing. * represents data that is significant with $p < 0.05$.

Subject	90°	135°
	P-value	P-value
Non-Swimmers	<.0001*	0.1864
Swimmers		

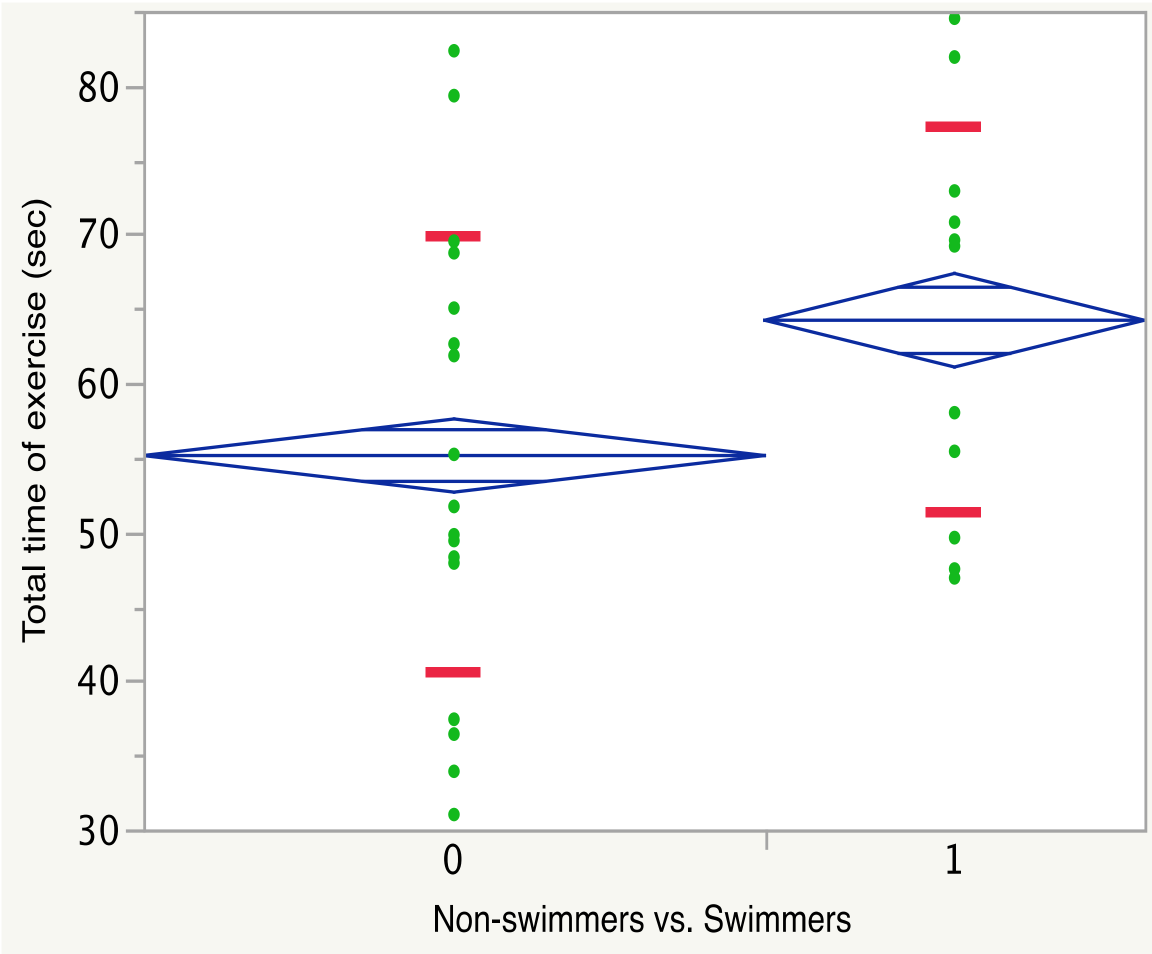


Figure 7. Graphical representation for total time subject held weight until time of fatigue at 90°. P-value of <0.0001. Blue-diamond shape represents confidence intervals of each group. Center line in diamond represents group means. Vertical span represents 95% confidence intervals for the mean of each group. Top point of diamond is upper 95%, bottom point of diamond is lower 95%. Lines above and below group mean are overlap marks that allow easier view for signs of significance. Horizontal span of diamond presents sample size tested. Green circles represent each subject tested. Red lines represent standard deviations. 0= Non-swimmers, 1= Swimmers.

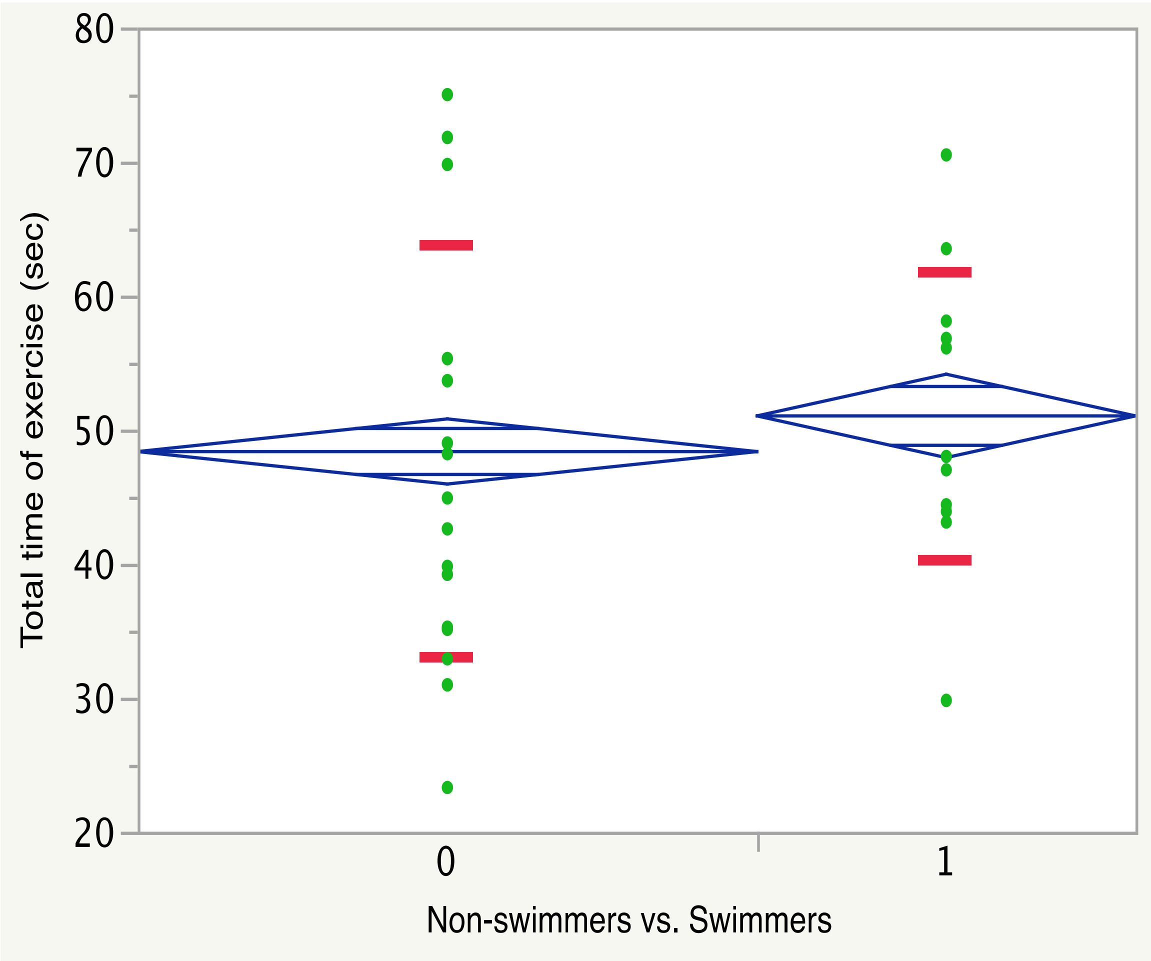


Figure 8. Representation for total time subject held weight until time of fatigue at 135°. P-value of 0.1864. Blue- diamond shape represents confidence intervals of each group. Center line in diamond represents group means. Vertical span represents 95% confidence intervals for the mean of each group. Top point of diamond is upper 95%, bottom point of diamond is lower 95%. Lines above and below group mean are overlap marks for variance. Horizontal span of diamond presents sample size tested. Green circles represent each subject tested. Red lines represent standard deviations. 0= Non-swimmers, 1= Swimmers.

Total time vs. Area of Tricep Lean Mass

Hypothesis 4 was to evaluate area of tricep lean mass in relation to how long a subject could perform an exercise. A bivariate analysis was run on these two components, and a regression line was created in order to obtain a R^2 value for the line that was graphed. The R^2 values obtained do not show strong correlation between the two variables in either angle that was tested. The R^2 values and the p-values for this set of data are represented in Table 5.

Figure 9 represents all subjects tested at 90° with a value of 0.0469. Figure 10 represents all subjects tested at 135° with a R^2 value of 0.1900. Even though the correlation is not strong that does not mean the data is not necessarily inadequate. After running an ANOVA on the data set, there does appear to be significance with p values <0.05 at the 90° and 135° angles with values of 0.0019 and <0.0001 respectively.

Shoulder Activity Scale

Hypothesis 5 was to test if a shoulder activity questionnaire can accurately aid in evaluating the strength of an individual's shoulder endurance. Subjects completed this questionnaire before testing, which rated them as high, average, or low in regards to daily use of their upper extremity. From these scores, means and standard deviations were calculated for each group, and are represented in Table 6. The mean score for the non-swimmer group was a 9.05 ± 3.22, and the mean for the swimmer group was 13.36 ± 3.93. Wilcoxon test was run on the data, and showed significance between the groups with p-value of <0.0001 (Table 6.)

Table 5. R^2 and p-values after comparing the total time to fatigue with the area of tricep lean mass at both angles tested. * indicates significant values within comparisons.

	90º	**135º**
R^2	0.0469	0.1900
p-value	0.0019*	<0.0001*

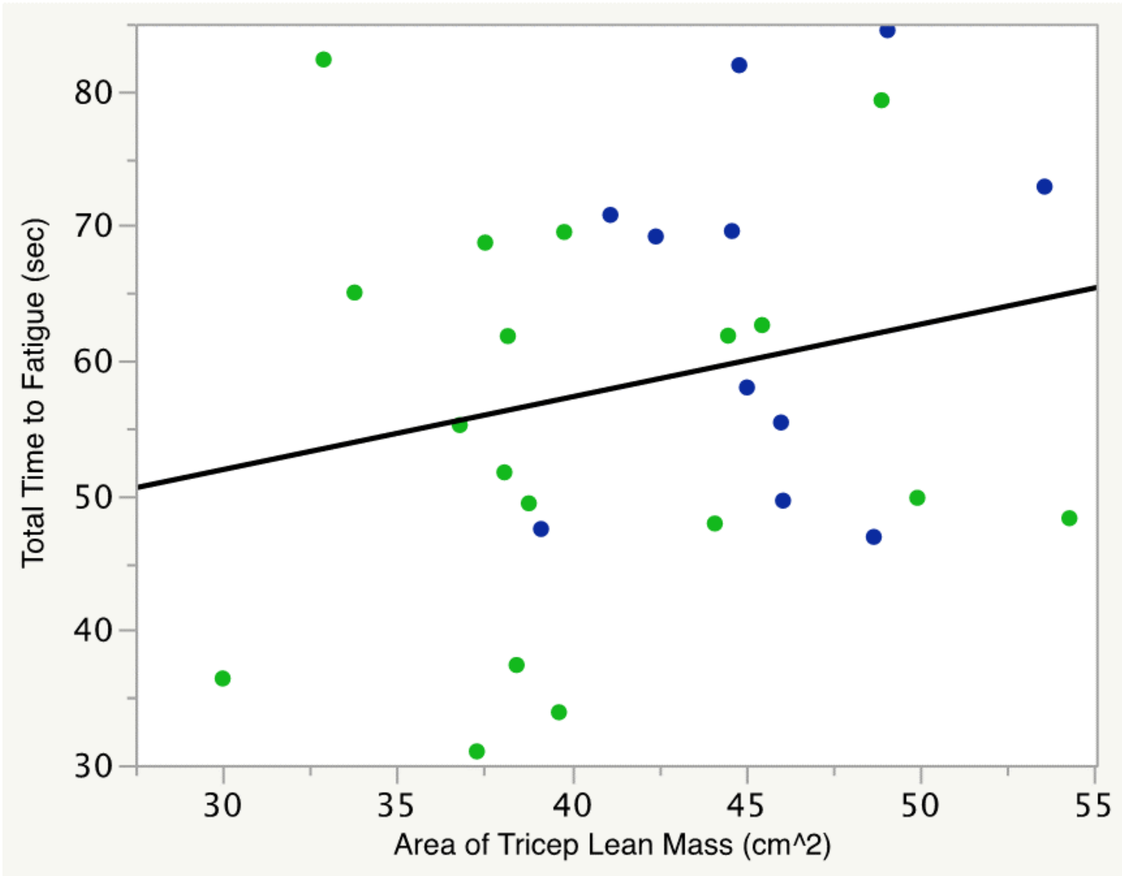


Figure 9. Bivariate analysis of total time to fatigue vs. the area of tricep lean mass in both groups at 90°; regression line with an R^2 value of 0.0469 and p-value of 0.0019. Green= Non-swimmers, Blue= swimmers

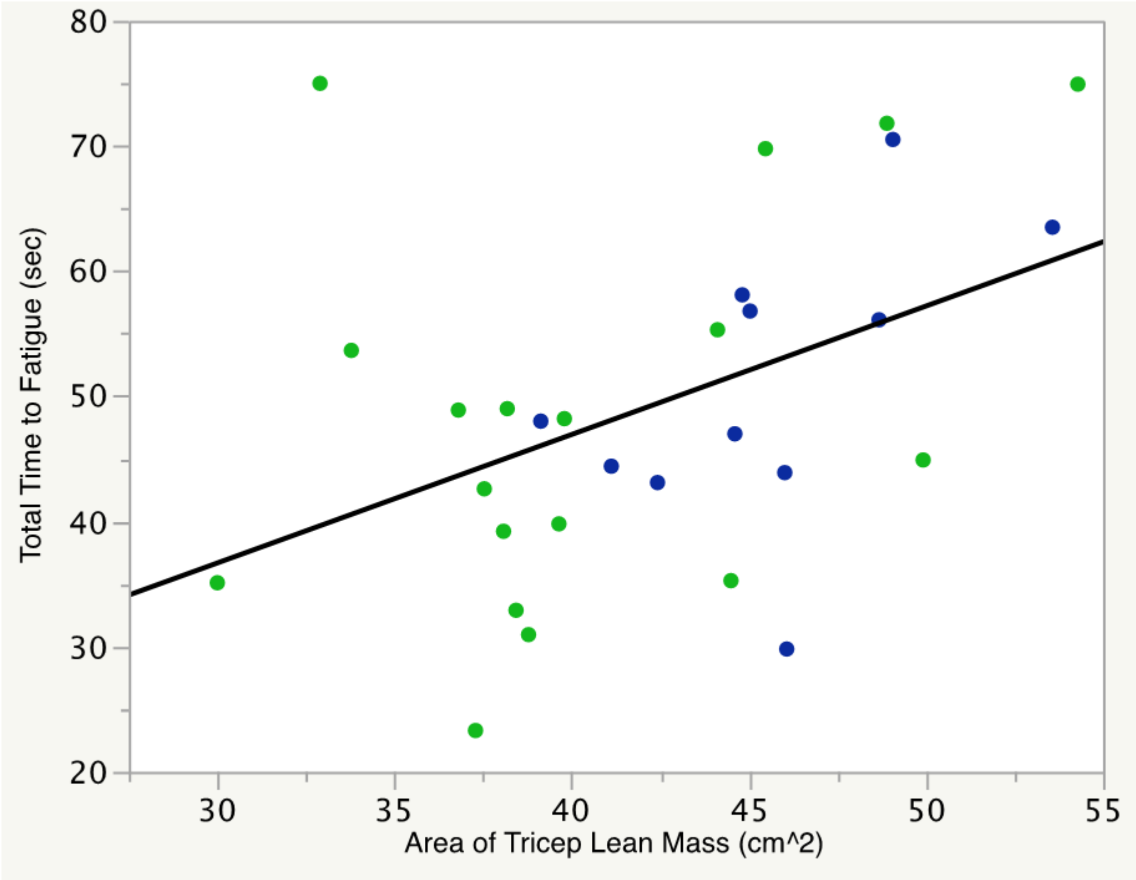


Figure 10. Bivariate analysis of total time to fatigue vs. the area of tricep lean mass in both groups at 135°; regression line with an R^2 value of 0.1900 and p-value of <0.0001. Green= Non-swimmers, Blue= swimmers

Table 6. Means and standard deviations of the scores obtained after subjects took the shoulder activity questionnaire. * indicates statistical significance between group means after performing a Wilcoxon's test. This data also with outliers taken out.

Subjects	**Mean ± SD**	**Wilcoxon's Test, p-value**
Non-Swimmers	9.05 ± 3.22	<0.0001*
Swimmers	13.36 ± 3.93	

DISCUSSION

The results obtained from this study in regards to the UT, PD, and LT fatiguing less in swimmers than in non-swimmers during an isometric exercise is expected. Major muscles involved in the recovery and glide-reach phase of the swim stroke include the UT, and the PD. As shown in Figure 1, during a freestyle stoke the UT and PD increase their activity in the early and mid-recovery phase in order to rotate the scapula forward (Heinlein and Cosgarea, 2010). Due to the hundreds of hours of aerobic training and thousands of freestyle strokes taken by swimmers on a weekly basis, less fatigue rates is to be expected. One of the main reasons for this would be the differences in muscle adaptation during exercise between the two groups. In females between the ages of 20-25, studies state that an average untrained person can uptake around 38mL of O2/min/kg during a strenuous exercise. For a trained athlete during the same exercise, their maximal O2 uptake can average around 74mL of O2/min/kg (Fox, 2011). This uptake ultimately affects the lactate threshold in the cell. Therefore lactic acid threshold of an untrained person will be less than that of a trained athlete, meaning that they will produce more lactic acid quicker and fatigue faster. If an athlete can produce less lactic acid during a given exercise, it makes them less subject to fatigue than an untrained person (Fox, 2011).

Another possibility that the swimmers showed less fatigue rates in UT could be from possible transition of different muscle fibers from years of repetitive overhead motion. This idea is taken from Scott et al. (2001) suggesting that motor units can change in size and can convert from one fiber type to another to adapt to training demands. As mentioned above, training demands in Division 1 swimming can be demanding. Research suggests that muscle fiber conversions between TIIX and TIIA are the most common among fiber conversions during constant training (Scott et al., 2001; Roy et al., 1999; Pette & Staron, 1997). This idea also coincides with the PD and the LT. Even though they are mostly composed of TI fibers, all fiber types adapt to training and therefore increase in the amount of mitochondria within the cell in order to provide more aerobic respiration (Fox, 2011).

The above statements can also be correlated with other significant results found in this current study. There was a significant difference in the fatigue rates of the PD at 135° and in the LT at 90°. The PD is used in conjunction with the middle deltoid and supraspinatus to aid in the extension and abduction of the humerus during arm rotations (Heinlein and Cosgarea, 2010), while the LT works in sync with the UT to rotate the scapula upward (Biel, 1997). Results from this study are also to be expected, as they are primary muscle involved in the early and mid-recovery phases of the freestyle stroke. It can be assumed that these muscles have been trained more, and therefore are able to uptake more oxygen for a decrease in fatigue rates.

The significant difference in the UT at 135º closely matches results that were obtained by Szucs et al. (2008). They found significance in the UT muscle activation during EMG testing depending on the angle at which the shoulder was being tested. Additionally they found that the greater the angle of shoulder placement during exercise, the higher the activation rate of the UT muscle (Szucs et al., 2008). This correlates with the results obtained in this current study, due to the significance found when the arm was held at a greater angle (Table 1 and 2). Szucs et al. also found that when performing an exercise in order to specifically fatigue the SA, there were actually higher activation rates of the trapezius muscle. During this study, none of the exercise performed specifically activate use of the SA, so having no signs of muscle fatigue in the SA is expected. This also goes along with the type of exercises that were performed during this study were strictly isometric. According to past research, isometric contractions are usually created under anaerobic conditions (Edwards et al., 1981). This suggests that muscles consisting of more TII fibers are activated before muscles that are composed of TI fibers.

The UT, PD, and LT were not the only muscles to show high fatigue rates in both groups. The INF did actually show values with the lowest negative SMDF values, there was just no significance that resulted between groups. If the INF is fatiguing at higher rates, then it is expected to see surrounding muscles possibly compensating for this, which could explain higher activation in above muscles. Examining this further is extremely important for swimmers due to the role that the INF plays in the rotator cuff, as rotator cuff injuries are one of the top causes of shoulder impingement amongst swimmers (Sein et al., 2010). If there is suboptimal activation of the INF, this could possibly lead to even higher rates of rotator cuff injuries amongst swimmers.

Overall Time to Fatigue

The expected results of swimmers being able to hold the time longer at both angles was not found during in this study. When analyzing the total time to fatigue during each exercise there was only significant results at the 90°. This suggests that muscles that are activated at this angle have higher TI fibers and have a higher lactic acid threshold than the in the swimmer group when compared to the non-swimmer group. There was no significant results in the total time held at 135°, but overall swimmers did hold the weight longer than non-swimmers.

SMDF values can be used to interpret these results because across all muscles at the 90° position, there are higher SMDF values than those at 135°. Remember that a lower SMDF values shows higher fatigue rates. Having higher SDMF values can correlate with how quickly the muscle will fatigue.

Subject Analysis of Shoulder Activity Scale

A questionnaire created by Brophy et al. (2005) helped develop a quick and easy way to gather information on test subjects regarding how much they use their upper extremities on a daily basis. This questionnaire scores subjects on a scale from 0-20 with 20 being the highest score; meaning highest rates of upper extremity use. They suggested that subjects with greater shoulder activity were ultimately expected to have better shoulder function (Brophy et al., 2005). They also mentioned that when creating this questionnaire it was important to account for playing an overhead sport due to more use of the shoulder.

Table 6 demonstrates the mean and standard deviation of the scores in each group. Scores that are ≥ 16 are rated at high upper extremity use, scores from 7-15 are rated as average use, and scores ≤ 6 are rated as lower use of the upper extremity (Brophy et al., 2005). By looking at the means and standard deviations of both groups, they would fall into an average rating for upper extremity use.

In order to see if there was any significance from these results to better interpret the above data, a Wilcoxon's test was used to obtain p-values. After running this test, there was a significant difference between the two groups, even though both of their mean scores would rate them under average. This helps accept the initial hypotheses of this research, suggesting that swimmers use their upper extremities more, and therefore will have less fatigue rates during exercise.

Tricep Lean Mass

Although there were low R2 values obtained in the results of the bivariate analysis, results of the ANOVA give p-values that are significant at different angles with results of 0.019 at 90° and <0.0001 at 135°. Even though there is some scatter present in the data, Figures 9 and 10 show that swimmers do tend to have larger areas of tricep lean mass than the non-swimmers. The line represented in the data also demonstrates that subjects with a larger area of tricep lean mass, do tend to hold the weight longer than those who have smaller areas of tricep lean mass. Further interpretation of this data could be useful when taking into consideration stroke specialties in swimmers and how much lean mass is present in different categories of swimmers.

CONCLUSIONS

Since no parameters were set when recruiting non-swimmer subjects, it was important to obtain history on the amount of hours they participated in exercise on a weekly basis to use in data interpretation. On the past medical history questionnaire subjects were able to choose certain increments in hours they exercised per week, which varied greatly amongst non-swimmer subjects. If this study is repeated, it would be suggested to put certain parameters on subjects recruited in regards to exercise on a weekly basis. One of the outliers that was taken out of the data analysis due to considerably smaller area of tricep lean mass than the rest of the subjects, also had the lowest score on the upper extremity questionnaire. Having subjects that all fell into this same category could possibly have given a different outcome with results.

Central vs. Peripheral Fatigue

As mentioned earlier in the introduction, there are two different types of fatigue that can occur in the overall muscle fatigue. Central fatigue tends to overtake control of peripheral fatigue due to factors in control of the CNS. When central fatigue takes place, there is a possibility that the muscle itself has not completely come to full fatigue.

This is another issue when testing for the validity of the results of this study. There is a chance that the subjects did not go to full peripheral muscle fatigue when participating in the study. A mechanism used to try and compensate for this issue was to cheer and encourage subjects as they performed each isometric exercise. There is still no certain way to tell if the subjects muscle came to full fatigue during each testing session, and it still something to take into account when using sEMG to analyze muscle fatigue in isometric exercises.

Limitations

There are several factors that need to be improved upon if this study were to be repeated. First, more Division 1 swimmers should be recruited to make sample sizes larger. There was a limitation to sample populations because there was only 1 women's swimming and diving team around the area where the study was being conducted. Having a larger sample size of swimmers, allows to make further interpretations in data analysis. This includes being able to categorize swimmers into distance, mid-distance, and sprinters. This could lead to more interesting findings on fatigue rates, because distance swimmers are more likely to have more TI fibers and fatigue at slower rates, where sprinters are most likely to have higher fatigue rates and be composed of more TII fibers. This was another limitation to this study because there were not enough swimmers in each category to make accurate statements regarding different training categories.

Another limitation to this study is that there were only 7 muscles tested. There is a possibility that other muscles could have been contributing to lower fatigue rates in muscles that were no able to be instrumented. This study could be repeated while focusing other large muscles involved in the freestyle stroke like the pectoralis major and the latissimus dorsi. Along with having restrictions on which muscles could be studied, another limitation was not being able to implement deeper muscles with sEMG. Needle EMG might be able to give more accurate results, and also be able to test muscles involved in the freestyle stroke like the supraspinatus.

Another limitation to this study was that the SA was tested, but an exercise to actually fatigue this muscle was taken out due to the primary researchers' discretion. The SA is largely affected by the recovery, and glide-reach phases of the freestyle swim stroke. Without being able to test this muscle, it put limitations on determinations that could be made in regards to fatigue.

The SA and the trapezius muscle work closely together in order to stabilize the scapula during movement. Past research shows that the SA, UT, and LT work together during arm elevation to rotate the scapula (Szucs et al., 2008; Ebaugh, McClure, & Karduna, 2006; Hess et al., 2005). The SA is considered to be a muscle that is responsible for keeping the scapula stable, and the trapezius' primary function is to act as a secondary stabilizer (Martins et al., 2008; Ekstrom et al.,2003; Dvir & Berme, 1978). In a study conducted by Pink et al. in 1991, they state that the SA may be more susceptible to higher fatigue rates in swimming because of its constant use during each stroke phase. They go on further to suggest that if there is less than optimal muscle fiber recruitment in the SA, this could lead to some type of shoulder impingement in swimmers (Lomax et al., 2014; Pink et al., 1991). If the UT was not able to compensate for fatigue rates in SA, this could possibly lead to shoulder impingement in swimmers. This similar idea is presented in multiple papers dealing with sEMG in looking at fatigue rates in these muscles (Szucs et al., 2008; Martens et al., 2015; Lomax et al., 2014). Another study by Martins et al. (2008) suggests that one reason there are lower activation rates in the SA is due to higher recruitment of other muscles in the shoulder complex (Martins et al., 2008). Looking at an exercise that activates the SA would be more of an optimal idea when looking for muscle fatigue rates in swimmers.

Final Conclusions

Results from this study do confirm original expectations that swimmers would be able to perform exercised longer than non-swimmers. What was not expected was that there was not a significant difference at both angles. This suggests that muscles that are activated more at 135° are fatiguing at higher rates, and therefore a type of rehabilitation program that focuses on exercises where the shoulder joint would be at this angle should be targeted.

Results also show that the muscles SMDF that have higher values suggest less fatigue, but there was only significant results in 3 muscles, and not in all 7. This could suggest that the UT, LT, and PD are trained more during the freestyle stroke and therefore have higher maximum uptake of oxygen in order to perform longer amounts of aerobic respiration than other muscles in the shoulder complex. This is due to large amounts of demanding training during the repetitive arm movements in the freestyle stroke. This suggests that training programs should therefore be focused on muscles to strengthen muscles that are not significantly different than non-swimmer groups like the INF and the MT. Ultimately, optimum strength in muscles of the shoulder complex is the goal in overhead athletes. Having less fatigue rates in surrounding shoulder muscles can lead to less muscle compensation in surrounding muscles, and a lesser chance for shoulder impingements.

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August 6, 2015

Neil Evans, DPT
Marshall University, School of Physical Therapy

RE: IRBNet ID# 781972-1
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Evans:

Protocol Title:	[781972-1] An Electromyography Study of Fatigability in Multiple Endurance Tests	
Expiration Date:	August 6, 2016	
Site Location:	MU	
Submission Type:	New Project	APPROVED
Review Type:	Expedited Review	

In accordance with 45CFR46.110(a)(4)(6)(7), the above study was granted Expedited approval today by the Marshall University Institutional Review Board #1 (Medical) Chair for the period of 12 months. The approval will expire August 6, 2016. A continuing review request for this study must be submitted no later than 30 days prior to the expiration date. The approval includes the recruitment email and flyer and the acknowledgement of the HIPAA authorization form.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

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IRB1 #00002205
IRB2 #00003206

August 17, 2015

Neil Evans, DPT
Marshall University, School of Physical Therapy

RE: IRBNet ID# 781972-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Evans:

Protocol Title:	[781972-2] An Electromyography Study of Fatigability in Multiple Endurance Tests
Expiration Date:	August 6, 2016
Site Location:	MU
Submission Type:	Amendment/Modification APPROVED
Review Type:	Expedited Review

The amendment to the above listed study was granted approval by the IRB #1 Vice Chair. This amendment adds one more surface electrode to the study on the contralateral erector spinae muscle group; gathers exercise specific data to be included on the research questionnaire; and gathers information on the Shoulder Activity Scale questionnaire, *et al.1*

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

MU SOPT Past Medical History Research Questionnaire

Date: ____________________________

Name: ______________________________ DOB: ____/____/_______ Age __________

Last *First* *Middle*

Gender: M/F

Address: _______________________________ City/State/Zip Code: _____________________

Occupation: ___________________ Phone Number: ( ) _________________

****** DO NOT WRITE IN THIS BOX: CLINICAL & RESEARCHER USE ONLY******

Weight: _________lbs Height: ____________ cm Arm Length: _________ cm

Exercise History:

1. On average how many hours do you exercise weekly? (Circle the BEST answer)

0-1 hr. 1-3 hrs. 3-5 hrs.

5-7 hrs. 7-9 hrs. 9+ hrs.

2. Do you use weights when exercising?

Yes No

3. If you answered yes to #2; how many hours per week do you use weights for your upper body?

0-1 hr. 1-3 hrs. 3-5 hrs.

5-7 hrs. 7-9 hrs. 9+ hrs.

4. Have you ever, or do you currently participate in competitive sports?

Yes No

5. If you answered yes to #4; how many years did you participate?

1-3 yrs. 4-6 yrs. 7-9 yrs. 10+yrs

6. If you answered yes to #4; what position or event did you play? **(List all that would apply for any sports)**

____

____

____

____

Past Medical History:

Do you have or had:

High Blood Pressure	Y	N
Lung Disease	Y	N
Diabetes	Y	N
Heart Disease	Y	N
Cancer	Y	N
Depression	Y	N
Osteoarthritis	Y	N
Back Pain	Y	N
Rheumatoid Arthritis	Y	N
Chronic Pain/Issues	Y	N
Major Injuries w/in last 6 months?	Y	N
Surgeries w/in last 1 year?	Y	N
Head Injuries w/in last 6 months?	Y	N

If yes to any of the above; please describe:

____

____

____

Shoulder Activity Scale[1]

Please indicate **with an "X"** how often you performed each activity in your healthiest and most active state, **in the past year.**

	Never or less than once a month	Once a month	Once a week	More than once a week	Daily
Carrying objects 8 pounds or heavier by hand (such as a bag of groceries)					
Handling objects overhead					
Weight lifting or weight training with arms					
Swinging motion (as in hitting a tennis ball, golf ball, baseball, or similar object)					
Lifting objects 25 pounds or heavier (such as 3 gallons of water) NOT INCLUDING WEIGHT LIFTING					

For each of the following questions, please **circle the letter** that best describes your participation in that particular activity.

1) Do you participate in contact sports (such as, but not limited to, American football, rugby, soccer, basketball, wrestling, boxing, lacrosse, martial arts, etc)?

   A No
   B Yes, **without** organized officiating
   C Yes, **with** organized officiating
   D Yes, at a professional level (ie, paid to play)

2) Do you participate in sports that involve hard overhand throwing (such as baseball, cricket, or quarterback in American football), overhead serving (such as tennis or volleyball), or lap/distance swimming?

   A No
   B Yes, **without** organized officiating
   C Yes, **with** organized officiating
   D Yes, at a professional level (ie, paid to play)

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1. Brophy RH, Beauvais RL, Jones EC, Cordasco FA, Marx RG. Measurement of shoulder activity level. *Clin. Orthop. Relat. Res.* Oct 2005;439:101-108.