The Effect of Fatigue on the Motor Evoked Potential of the Infraspinatus

Joseph Howard Cordell
Western Washington University, joseph@jcordell.com

Follow this and additional works at: https://cedar.wwu.edu/wwuet
Part of the Kinesiology Commons

Recommended Citation
https://cedar.wwu.edu/wwuet/627
THE EFFECT OF FATIGUE ON THE MOTOR EVOKED POTENTIAL OF THE INFRASPINATUS

By

Joseph Howard Cordell

Accepted in Partial Completion of the Requirements for the Degree Master of Science

ADVISORY COMMITTEE

Chair, Dr. Jun G. San Juan

Dr. Kelly J. Jantzen

Dr. David N. Suprak

GRADUATE SCHOOL

Dr. Gautam Pillay, Dean
Master’s Thesis

In presenting this thesis in partial fulfillment of the requirements for a master’s degree at Western Washington University, I grant to Western Washington University the non-exclusive royalty-free right to archive, reproduce, distribute, and display the thesis in any and all forms including electronic format, via any digital library mechanisms maintained by WWU.

I represent and warrant this is my original work, and does not infringe or violate any rights of others. I warrant that I have obtained written permissions from the owner of any third party copyrighted material included in these files.

I acknowledge that I retain ownership rights to the copyright of this work, including but not limited to the right to use all or part of this work in future works, such is as articles or books. Library users are granted permission for individual, research and non-commercial reproduction of this work for educational purposes only. Any further digital posting of this document requires specific permission from the author.

Any copying or publication of this thesis for commercial purposes, or for financial gain, is not allowed without my written permission.

Joseph Cordell

11/16/17
The Effect of Fatigue on the Motor Evoked Potential of the Infraspinatus

A thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Joseph Cordell
November 2017
Abstract

Shoulder muscle dysfunction can lead to glenohumeral incongruity and can negatively affect glenohumeral joint stability. Fatigue of the infraspinatus could affect joint stability. The purpose of this study was to examine the effects of fatigue on the muscle activation of the infraspinatus, specifically, the motor evoked potential (MEP) amplitude, peak-to-peak duration, and activation latency of the MEP. Eighteen healthy college age students (eleven males, seven females) participated in this study. Subjects were screened for history of head trauma, shoulder pain, shoulder surgery, any neuromuscular disorders and potential conditions that might place them at a higher risk for adverse effects of transcranial magnetic stimulation.

Subjects were instrumented with two electrodes on the infraspinatus. Maximal voluntary contraction of humeral external rotation was recorded before and after fatigue. The subjects held their right arm parallel to the floor at 45° of scapular abduction to induce muscle activation of the infraspinatus during stimulation. Stimulations were given before and after fatigue over the motor cortex directly involved with the infraspinatus. The fatigue protocol consisted of the subject holding onto a TheraBand and performing external rotations until fatigued.

Paired t-tests were used to compare MEP amplitude, peak-to-peak duration, and activation latency before and after fatigue. Following fatigue, there was a significant effect on peak-to-peak duration ($p = 0.0005; r = -.50$). No significance was found in MEP amplitude and muscle activation latency. In conclusion, peak-to-peak duration increased but it is unknown how this might change muscular activation in a fatigued state.
Acknowledgements

I would to give thanks and appreciation to Dr. Jun San Juan for giving me support and encouragement throughout my time in the graduate program. He has continually shown a positive attitude and great patience while working with me on this project. Thank you Dr. Lorrie Brilla for your guidance during my time at Western Washington University. Through thick and thin you have had my back when I needed it.

For Dr. Jun San Juan, Dr. Kelly Jantzen, and Dr. Dave Suprak, thank you for being on my committee and helping with thesis. With your guidance and input, I have learned a lot from all of you. I want to thank William McGinnis and Josh Larussa for assisting me in data collection. This thesis would not have been completed without either of you.

Finally, I owe and great amount of thanks to my friends and family for supporting me, helping me and being there for me during my academic endeavors. This has been a long journey and the next one is just about to begin.
# Table of Contents

Abstract ................................................................................................................................. iv
Acknowledgements .................................................................................................................. v
List of Figures and Tables ....................................................................................................... ix
List of Appendices .................................................................................................................. x

Chapter I: The Problem and Its Scope

Introduction ............................................................................................................................. 1
Purpose of the Study ............................................................................................................... 3
Experimental Hypothesis ...................................................................................................... 3
Significance of the Study ...................................................................................................... 3
Limitations of the Study ....................................................................................................... 4
Definition of Terms ............................................................................................................... 5

Chapter II: Review of Literature

Introduction ............................................................................................................................. 6
Anatomy of the shoulder ....................................................................................................... 7
Shoulder Musculature .......................................................................................................... 8
Fatigue ................................................................................................................................. 8
Biomechanics of fatigue ..................................................................................................... 11
Fatiguing protocols .............................................................................................................. 12
Transcranial magnetic stimulation and the relation to fatigue ............................................ 13
Summary .............................................................................................................................. 17

Chapter III: Methods and procedures

Introduction ............................................................................................................................. 18
Description of study population ................................................................. 18
Design of study .......................................................................................... 18
Data collection procedures ........................................................................ 19
  Instrumentation ....................................................................................... 19
  Surface Electromyography ...................................................................... 19
  Transcranial Magnetic stimulation ......................................................... 19
  Force Production ...................................................................................... 21
Measurement techniques and test procedures ........................................ 22
Data processing ......................................................................................... 25
Data analysis ............................................................................................. 25

Chapter IV:

Introduction ............................................................................................. 26
Results ..................................................................................................... 26
  Peak-to-Peak MEP Duration .................................................................. 26
  MEP Amplitude ..................................................................................... 28
  Muscle Activation Latency .................................................................... 28
Discussion ............................................................................................... 29
...................................................................................................................... 32

Chapter V: Summary Conclusions and Recommendations

Summary .................................................................................................. 33
Conclusions ............................................................................................. 33
Recommendations ................................................................................... 33
References ............................................................................................... 34
Appendices ........................................................................................................................................... 45
List of Figures and Tables

Figure 1. Customizable Chair .................................................................21

Figure 2. Force production testing ..................................................................22

Figure 3a. Mapping procedure with Brainsight software ................................23

Figure 3b. Stimulation process ..........................................................................23

Figure 4. Fatigue Protocol ................................................................................24

Figure 5. Sample MEP from single subject .....................................................27

Figure 6. A graphical comparison of average peak-to-peak duration ...............27

Figure 7. A graphical comparison of average MEP amplitude .............................28

Figure 8. A graphical comparison of average muscle activation latency ................29

Table 1. Mean and standard deviation ...............................................................26
List of Appendices

Appendix A. Consent Form .................................................................................................................. 45
Appendix B. Transcranial Magnetic Stimulation Screening Questionnaire ........................................... 47
Appendix C. Protocol Checklist .......................................................................................................... 52
Appendix D. Photograph & Video Release Form .................................................................................. 53
Appendix E. Raw Data ......................................................................................................................... 54
Chapter I
The Problem and Its Scope

Introduction

The shoulder contains complicated groups of muscles, tendons, ligaments, and bursae all involved in humeral and scapular kinematics (Terry & Chopp, 2000). Regular use of the arms can result in fatigue of shoulder musculature, which could lead to altered scapular kinematics during humeral elevation (Tsai, McClure, & Karduna, 2003). These changes in scapular kinematics can potentially lead to shoulder problems such as impingement syndrome, rotator cuff tears, and glenohumeral instability (Ebaugh, McClure, & Karduna, 2006). It is important to investigate the effects of fatigue on individual shoulder muscles to further understand their role in shoulder injuries. This could help prevent future shoulder injuries that are commonly present amongst many jobs, such as cello players, welders, slaughterhouse workers, plate workers and dentists (Frost & Andersen, 1999; M. Hagberg & Wegman, 1987; Mats Hagberg, 1996; Rickert, Barrett, Halaki, Driscoll, & Ackermann, 2012).

The rotator cuff plays a major role in the positioning and stabilization of the humeral head during arm movement (Lin, Christie, & Karduna, 2015). In particular, the infraspinatus is involved in external rotation and stabilization of the humerus as a humeral head depressor by pulling the humerus towards the glenoid fossa of the scapula (Ngomo, Mercier, & Roy, 2013). There was an increase in superior translation of the humeral head while using a nerve block to cause dysfunction of the infraspinatus and supraspinatus. This increase is also often seen in individuals experiencing shoulder impingement syndrome (San Juan, Kosek, & Karduna, 2013). Reddy, Mohr, Pink, & Jobe (2000) found that the infraspinatus showed a significant decrease in electromyographic activity during humeral elevation when comparing subjects with shoulder
impingement syndrome to a control group. This suggests that the infraspinatus is an essential muscle to investigate regarding alterations in activity due to fatigue. A good amount of studies have examined infraspinatus functions and fatigue peripherally (D. Ebaugh et al., 2006; Reddy et al., 2000; Tsai et al., 2003), but none have examined the effects of fatigue on the infraspinatus centrally.

Muscle contraction is not instantaneous from cortex activation; there is a latency that occurs between motor cortex stimulation and response (Matamala et al., 2013). Signals from the motor cortex are influenced by the central nervous system and are sent from the motor cortex via efferent neurons to motor neurons in the spinal cord. When motor neurons are stimulated, there is a depolarization of the sarcolemma, which results in muscular contraction at the level of the sarcomere. In theory, changes in latency could have an effect on overall joint stability and this might lead to complications in the joint area and potential pain and injury. In the shoulder, when the humerus changes position, there needs to be a balance between the superior and inferior forces holding the shoulder in place in order to ensure proper usage (Reddy et al., 2000). There is a possibility that a fatigued muscle may disrupt the balance of forces during movement and cause injury over a period of time. When muscles are fatigued, there is an increase in the amount of motor units recruited to perform the same movement (Reddy et al., 2000).

To assess central fatigue, transcranial magnetic stimulation (TMS) can be applied to the motor cortex to stimulate target muscles. Several studies demonstrate changes in corticomotor excitability during and after muscle fatigue (Brasil-Neto et al., 1993; McKay, Tuel, Sherwood, Stokić, & Dimitrijević, 1995). With TMS, it is possible to find the latency and amplitude of activation of the infraspinatus before and after fatigue. This can be applied to examining the changes in the motor evoked potential (MEP) of muscles. The information gathered might be used to infer how changes in motor patterns may affect joint stability. Authors have used TMS to assess changes in motor patterns of the vastus medialis, vastus medialis oblique, and vastus
lateralis in the presence of patellofemoral pain (On, Uludağ, Taşkiran, & Ertekin, 2004; Tsao, Galea, & Hodges, 2008).

Not much research has been done to determine if there is an alteration in the MEP of the infraspinatus following a fatiguing exercise. Research has examined the MEP of the first dorsal interosseous, quadriceps muscles, and back extensor muscles (Brasil-Neto et al., 1993; Liepert, Kotterba, Tegenthoff, & Malin, 1996; McKay et al., 1995; Samii, Wassermann, Ikoma, Mercuri, & Hallett, 1996).

**Purpose of the Study**

The purpose of this study was to examine the change in muscle activation latency, amplitude of the MEP and peak-to-peak duration of the infraspinatus following fatigue. The cause of shoulder impingement syndrome is still uncertain, and this study could lead to further insights as to the inner mechanisms of this condition.

**Experimental Hypothesis**

The hypothesis is that there will be a significant increase in muscle activation latency, peak-to-peak duration, and amplitude of MEP at the infraspinatus muscle in response to a fatiguing protocol.

**Significance of the Study**

Using a fatigue test to determine if there is a change in the MEP of the infraspinatus could help identify the factors that lead to alterations in glenohumeral kinematic patterns and shoulder pathology. A change in kinematic patterns and shoulder external rotator muscle strength and endurance have been identified in shoulder impingement syndrome, rotator cuff tears, and glenohumeral instability (Ebaugh et al., 2006; Tsai et al., 2003).
Limitations of the Study

1. These results apply only to healthy college aged subjects, so caution should be used when extrapolating the results to patient populations.

2. Surface EMG was used for the infraspinatus. There is a chance of cross talk from neighboring muscles. This chance is minimized through proper placement of the EMG electrode.

3. Since the subjects in this experiment have no record of shoulder or neurological conditions, the results from this study are limited to those who are asymptomatic.

4. Fitness levels may affect the rate of fatigue and recovery from fatigue, activity level may influence the results from this study.
**Definition of Terms**

**Dyskinesis:** altered scapular motion and position (Kibler, Press, & Sciascia, 2012).

**Central Fatigue:** failures at or above the spine that result in insufficient muscle activation (Allen, Lamb, & Westerblad, 2008; Vøllestad, 1997)

**Fatigue:** A exercise-induced reduction in maximal voluntary muscle force (Gandevia, 2001; Gandevia, Allen, Butler, & Taylor, 1996)

**Kinematics:** Measurements of the joints concerned with the motion of the body, without reference to the forces that cause the movement (Whiting & Zernicke, 2008).

**Peripheral Fatigue:** resulting insufficiency at the muscle due to imbalances of key minerals or substrates, leading to inadequate contractive abilities within the muscle (Allen et al., 2008)

**Motor Evoked Potential (MEP):** a brief, synchronous muscle response to brain stimulation (Hallett, 2007)

**Shoulder impingement:** the entrapment, compression, or mechanical irritation of the rotator cuff structures and/or long head of the biceps tendon either underneath the coracoacromial arch or between the undersurface of the rotator cuff and the glenoid or glenoid labrum (Ludewig & Reynolds, 2009)

**Synovial joint:** highly mobile articulations with a characteristic joint cavity that is formed by bones connected with ligaments and separated by a joint capsule (McGinnis, 2013). bony surfaces within the joint capsule are lined with a synovial membrane and the membrane secretes synovial fluid for lubrication for the synovial joint (McGinnis, 2013)

**Transcranial magnetic stimulation (TMS):** a device that uses a brief, high-current pulse through a magnetic coil that produces a magnetic field that may excite neurons in the brain (Hallett, 2007)
Chapter II

Review of Literature

Introduction

Humeral movement and its range of motion are made possible by the muscles, tendons, ligaments and bursa within the shoulder. This movement occurs around the glenohumeral (GH) joint and relies on the scapula for efficient movements (Paine & Voight, 2013). During movement, only 25-30% of the humeral head is in contact with the glenoid fossa of the scapula (Terry & Chopp, 2000) which makes the joint unstable when compared to joints with higher rates of contact. This makes the GH joint a pseudo ball-in-socket joint in the fact that it relies on ligaments and muscular stabilizers to maintain the position of the humeral head throughout humeral motion (Myers & Lephart, 2000).

The GH joint has the greatest range of motion because of both static, dynamic, and bony stabilizers (Lee, Kim, O’Driscoll, Morrey, & An, 2000; Lugo, Kung, & Ma, 2008; Terry & Chopp, 2000). The static stabilizers include the labrum, joint capsule, and the GH ligaments, while the rotator cuff is a dynamic stabilizer of the GH joint (Lugo et al., 2008). There are four muscles that makes the rotator cuff and they are the subscapularis (internally rotates the humerus), supraspinatus (abducts the humerus), infraspinatus (externally rotates the humerus), and the teres minor (externally rotates the humerus). When these four muscles act in concert, the humeral head is compressed into the joint, and during arm movement, is steered into the correct position (Dashottar, Costantini, & Borstad, 2014). If there is a chance that these muscles act out of concert, it is possible that the humeral head may not be in the most optimal position and this could lead to injury of the shoulder. If an individual muscle is fatigued, there might be an altered effect on how the muscles synchronizes with the movements of the other muscles. Muscle
dysfunction will lead to GH incongruity and can negatively affect GH joint stability (DePalma & Johnson, 2003; Halder, Zhao, O’Driscoll, Morrey, & An, 2001; Lugo et al., 2008)

Muscle fatigue is an exercise-induced reduction in maximal voluntary muscle force (Gandevia, 2001; Gandevia, Allen, Butler, & Taylor, 1996). There are two different categories for fatigue: central and peripheral (Allen, Lamb, & Westerblad, 2008; Gandevia, 2001). Central fatigue occurs when the central nervous system fails to coordinate motoneurons properly (Gandevia, 2001). Peripheral fatigue occurs during an imbalance of minerals and substrates within the muscle structures (Vøllestad, 1997).

Transcranial magnetic stimulation (TMS) is a non-invasive, safe, and painless method that activates the motor cerebral cortex (Hallett, 2007). With TMS, areas of the brain can be activated or inhibited using magnetic waves and these effects can be used to localize brain functions (Hallett, 2007). TMS has been used in numerous studies to evaluate the corticospinal stimulation of the upper limb distal muscles such as the first dorsal interosseous. Research has also examined effects on upper limb proximal muscles such as the deltoid and infraspinatus. When examining cortical excitability using EMG to monitor muscle activation, various studies have demonstrated that there are changes in excitability depending on the status of the muscle and the position of the humerus (Gritsenko, Kalaska, & Cisek, 2011; Kantak et al., 2013; Lin, Christie, & Karduna, 2015). It is possible to examine the changes in muscle activation from a central stimulation point before and after fatigue by using TMS.

**Anatomy of the shoulder.** The scapula is unique in that it is not attached to the trunk directly, but rests on the serratus anterior and the subscapularis muscles making the scapula pivotal in generating force for humeral movement. This disconnection permits scapular mobility in many directions, such as retraction, protraction, elevation, depression, anterior/posterior tilt, external/internal and upward/downward rotation (Paine & Voight, 2013). During humeral
motion, the scapula provides a stable base and helps with the transfer of energy (Paine & Voight, 1993; Voight & Thomson, 2000). The scapula is not the only device that supports upper extremity movement, but movement is also assisted by the acromioclavicular, sternoclavicular, and scapulothoracic joints that are within the shoulder (Hawkes et al., 2012). The acromioclavicular joint is a synovial joint located superior to the GH joint and consists of the junction between the acromion and the clavicle. The sternoclavicular joint is a synovial saddle joint between the manubrium of the sternum and the clavicle bone. The scapulothoracic joint is the muscular interaction between the scapula and the thorax and is not a true anatomic joint. A function of the scapulothoracic joint is to increase the range of motion for the humerus and to add a large lever for the muscles that attach to the scapula (Voight & Thomson, 2000). These joints and bony structures work in unity in order to maintain proper scapular kinematics during daily tasks.

The head of the humerus fits into the glenoid fossa and forms the glenohumeral (GH) joint. The GH joint is a multiaxial ball-and-socket-synovial joint that offers the greatest range of motion and movement potential of any other joint in the body, but in exchange stability is sacrificed (Lin et al., 2015). The static and dynamic forces of the muscles and ligaments holding the GH joint in place affect the stability. When the humerus and scapula move in unison there is a need for GH alignment in order to maintain maximum joint stability; this is called scapulohumeral rhythm (Kibler, Press, & Sciascia, 2012).

**Shoulder musculature.** The humerus has a large range of motion due to the lack of bony articulations between the trunk and scapula. With a large range of motion there is a dependence on active control to stabilize the scapula (Paine & Voight, 2013). The main stabilizers of the scapula are the serratus anterior, rhomboid major and minor, levator scapulae, and upper and lower trapezii (Paine & Voight, 2013). Stability of the scapulothoracic joint depends on the coordination of the surrounding musculature (Paine & Voight, 2013). Dysfunction or weakness
in the scapular musculature alters mechanics and positioning of the scapula and may lead to alterations in the biomechanics of the GH joint (Paine & Voight, 1993; Voight & Thomson, 2000). An unstable scapular base may affect the center of rotation of the GH joint and alter the length-tension relationship of the muscles involved in humeral movement (Joshi, Thigpen, Bunn, Karas, & Padua, 2011). There is a possibility that any inefficiency in scapular stabilization could cause a decrease in neuromuscular performance and possibly predispose the individual to injury of the GH joint (Paine & Voight, 1993; Voight & Thomson, 2000).

The rotator cuff is a grouping of muscles on the scapula that consists of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles (Jobe & Pink, 1993; Kamkar, Irgang, & Whitney, 1993). The rotator cuff has the ability to rotate, depress, and stabilize humeral head within the GH joint. The persistent force pulls the humeral head into the glenoid fossa during arm movement in order to stabilize it into position (Lee et al., 2000; Yanagawa et al., 2008). The infraspinatus and the subscapularis are the external rotators and humeral stabilizers (D. Ebaugh, McClure, & Karduna, 2006). The infraspinatus is a key external rotator of the humerus and, because it is the only muscle of the rotator cuff accessible with surface EMG, offers a convenient entry point for studying the role of fatigue in rotator cuff function (Lin et al., 2015; Ngomo, Mercier, & Roy, 2013). The infraspinatus also has a role in keeping the humeral head stabilized and separated from the glenoid within the GH joint. Consequently, a weak or damaged infraspinatus could lead to instability of the humeral head (Werner et al., 2006) and further lead to shoulder impingement syndrome (Hébert, Moffet, McFadyen, & Dionne, 2002).

Fatigue. Muscle fatigue can be defined as the reduction of force generated by a muscle, or a group of muscles, after sustained or repeated contractions (Eichelberger & Bilodeau, 2007; Merton, 1954). During fatigue, there are adaptations in the entire motor system (Zghal et al., 2015). These adaptations occur at different sites of the motor system such as muscle fiber, muscle fiber membrane, neuromuscular junction, motoneurons, segmental and supraspinal
circuits (Taylor & Gandevia, 2001). Research has noted that neuromuscular fatigue is task specific (Enoka & Stuart, 1992) such as endurance tasks or maximal exertions.

Fatigue has been attributed to two categories, central (i.e. nervous systems) and peripheral (i.e. muscular) (Martin et al., 2010). Central fatigue can be defined as the progressive decrease in muscle activation due to a decrease in neural drive (Gandevia, 1992). The supraspinal component of central fatigue have been found to occur after extended periods of low-force contractions rather than maximal efforts (Søgaard, Gandevia, Todd, Petersen, & Taylor, 2006; Taylor & Gandevia, 2008; Zghal et al., 2015). These periods have ranged from 2-4 minutes (Bilodeau, 2006; Gandevia, 2001; Gandevia et al., 1996). But these alterations in corticomotor excitability have been found in both sustained voluntary maximal or submaximal isometric muscle contractions (Kotan, Kojima, Miyaguchi, Sugawara, & Onishi, 2015). When examining central fatigue during a sustained maximum voluntary contraction (MVC), there is a decrease in motor firing rates, the alteration in firing could mean that the motoneuron activity could be suboptimal (Taylor & Gandevia, 2001).

There are many theories as to why central fatigue occurs. One is that afferent fibers have free nerve endings that are sensitive to various stimuli such as mechanical, thermal and chemical and the sensitivity of these afferents may affect supraspinal responses(Taylor & Gandevia, 2008). Another theory to central fatigue is that it is a self-preservation mechanism that maintains homeostasis and protects vital functions(Noakes, 2012).

Endurance training when compared to strength training influences central fatigue recovery. Triscott et al. (2008) examined the recovery time and reduction in MEP amplitude of sedentary, endurance, and strength trained athletes at and after an endurance exhaustion task. Reductions of cortical excitability were found for sedentary, endurance and strength trained subjects, but endurance athletes recovered the quickest followed by sedentary and last was
resistant-trained athletes. Endurance training has been seen to delay central fatigue; this was attributed to a greater tolerance of peripheral fatigue by the central nervous system suggests that the sensory threshold of the III/IV muscle afferents could have been up-regulated and/or that specific adaptations would have occurred within the supraspinal structures (Zghal et al., 2015). The same study by Zghal et al. (2015) stated that recovery is not affected by endurance training.

Peripheral fatigue is the result of insufficiency at the muscle due to imbalances of key minerals or substrates, leading to inadequate contractive abilities within the muscle (Allen et al., 2008). There are many hypothesis as to the causes of peripheral fatigue, ranging from an increased concentration of cellular inorganic phosphate (Allen et al., 2008; Takagi, Shuman, & Goldman, 2004; Westerblad, Allen, & Lännergren, 2002) to the rate of myosin light chain phosphorylation (Allen et al., 2008; Bottinelli & Reggiani, 2000; MacIntosh, Holash, & Renaud, 2012). Another factor of peripheral fatigue is muscle fiber type. Type I fibers, slow twitch, are more fatigue resistant compared to type IIa and type IIx fibers, fast twitch (Vøllestad, 1997).

Each muscle is made of varying concentrations of type I, IIa IIx fibers, the infraspinatus is made of 29 ± 10% type IIx, 23 ± 11% IIa, and 48 ± 14% type I fibers (Srinivasan, Lungren, Langenderfer, & Hughes, 2007). The distribution of fiber type in the infraspinatus could affect the rate that fatigue occurs and the rate of recovery as well.

**Biomechanics of shoulder fatigue.** Repetitive arm use can cause fatigue of shoulder muscles and this has been a potential link to the development of shoulder pain. A reduction in force generation of shoulder muscles might lead to a reduction in control or stabilization for joint motions, such as the GH joint (McQuade, Dawson, & Smidt, 1998; San Juan, Kosek, & Karduna, 2013). The infraspinatus has been seen to play a significant role in the alteration of GH kinematics when fatigued while other shoulder musculature, such as the anterior/posterior deltoid and serratus anterior, did not alter GH kinematics while fatigued (Ebaugh, McClure, & Karduna, 2006). Altered scapular kinematics have been found after fatiguing external rotators such as the
infraspinatus. (Ebaugh et al., 2006; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Tsai et al., 2003). Tsai et al. (2003) reported decreased scapular posterior tilt, upward rotation, and external rotation during arm elevation after the external rotators were fatigued. Ebaugh et al. (2006) confirmed a decrease in scapular posterior tilt from external rotator fatigue, but also noted an increase in scapular upward rotation at 60° of arm elevation. Joshi et al. (2011) also stated an increase in scapular upward rotation with arm elevation following fatigue.

**Fatiguing protocols.** Shoulder fatigue caused by repetitive arm motions could lead to the development of shoulder pain (Hawkes et al., 2012). Strategies for inducing infraspinatus fatigue include isometric contraction or repetitive shoulder external rotations. A study done by Ebaugh et al. (2006) measured force production of external rotation using isometric contractions with a load cell while the subject lay on their non-measured side. Subjects were asked to alternate between holding external rotation of 0° while blindly identifying objects by hand using touch followed by 20 repetitions of shoulder external rotation against resistance, and then raising their hand until their forearm was parallel to the floor and lowering the arm while holding a weight that was 20% of the force produced in the MVC (for example, if they produced ten pounds of pressure the weight would be two pounds). Fatigue was determined when subjects were unable to continue the required activities and force was decreased by at least 25%.

Tsai et al. (2003) used a green Thera-Band while having the subjects externally rotate their shoulders from 45° in internal rotation into a neutral position at a rate of 1 Hz. Fatigue was determined if there was a decrease in force output that was greater than 25% of the pre-fatigue measured force. If the subject was not considered fatigued, then they continued with the protocol.

In a study by Dashottar et al. (2014), a 40% force reduction was used as a criterion of fatigue determined by external rotation force testing. Fatigue was induced in subjects that were
laying on their sides by repeatedly raising and lowering the forearm starting in maximum internal rotation while holding a dumbbell that was approximately 5% of their body weight. Again, if the subject was able to produce a force that was not decreased by 40% of their max force then they continued the fatiguing protocol.

With various studies and fatigue protocols previously used, majority of the studies had a continuous movement in order to induce fatigue of the infraspinatus rather than an isometric contraction. Most had their subjects laying on their opposite side of the target infraspinatus and used gravity to assist in fatiguing the muscle. The use of Thera-Band as a form of resistance seems most appropriate when the subject is required to be seated throughout the testing. Using a Thera-Band does not ensure that each subject experience the exact same resistance, but each subject would experience a similar resistance regardless of training status.

**Transcranial Magnetic Stimulation and the relation to fatigue.** Transcranial magnetic stimulation (TMS) is a noninvasive transcranial stimulation technique that can be used for assessing central motor pathways (Saypol, Roth, Cohen, & Hallett, 1992). The first study published with TMS was Berker et al. (1985) and this was to prove that it is possible to stimulate the brain with magnetic stimulation rather than using electrical stimulation, which was the current method of motor stimulation. Magnetic stimulation is caused by a short high-current pulse through a coil of wire, this electric pulse causes a magnetic fields to flow around the coiled wire that are parallel to the plane of the coil and are generally tangential in the brain (Hallett, 2007; Saypol et al., 1992). The neuronal components are activated with the magnetic field emitted from the coil (Hallett, 2007). TMS has been used in the field of Neuroscience to investigate Parkinson’s disease, dystonia, stroke, and depression (Hallett, 2007). With TMS, it might be possible to examine specific muscle functions in relation to central activation. When TMS is used over the motor cortex, there is an excitatory response called a motor evoked potential (MEP) from the activated muscle (Rothwell, Thompson, Day, Boyd, & Marsden,
The MEP from TMS relies on both the excitability of the corticospinal tract and the excitability of motoneurons, which are influenced by inputs from spinal interneurons and monosynaptic projections from muscle spindle afferents (Gritsenko et al., 2011) meaning that both central and peripheral mechanics can affect the MEP. With the testing of fatigue and its relation to MEP, several studies have shown a decrease in MEP amplitude with a passive muscle (Kotan et al., 2015).

For reliable positioning of the magnetic coil of the TMS for stimulation, the international 10-10 system for EEG electrode placement is commonly utilized. This system describes the location and placement of scalp electrodes. Using bony landmarks on the skull, the 10-10 system places points of interest by a fixed distance of 10 or 20% while taking head size into consideration (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003). The bony landmarks that the systems use to adjust to an individual’s head includes the nasion, inion and preauricular points. The TMS is applied in a grid around a coordinate origin in order to map out the brain and find the spot that most excites the target muscle (Fadiga, Craighero, Buccino, & Rizzolatti, 2002). These methods give a starting point to focus on when mapping out muscles. The primary motor cortex is located along C5 to C6 of the international 10-10 system. Shoulder muscles representation in the primary motor cortex are located near C1 and C2 of the international 10-10 system in comparison to the motor homunculus. A motor homunculus is a 2D representation of body parts placed over their corresponding activation areas of the motor cortex (Schott, 1993).

The MEP is followed by a silent period and is a pause in ongoing voluntary EMG activity. (Burle, Bonnet, Vidal, Possamaï, & Hasbroucq, 2002; Damron, Dearth, Hoffman, & Clark, 2008; Taylor, Allen, Butler, & Gandevia, 1997). The first part of the silent period is from spinal cord refractoriness and the second part is from cortical inhibition (Hallett, 2007; Siebner, Dressnandt, Auer, & Conrad, 1998) The silent period is calculated as the interval from TMS delivery to the continuation of voluntary EMG (Damron et al., 2008). The silent period has been
noted to reflect the recruitment of inhibitory cortical interneurons (Davey, Ramaiguère, Maskill, & Ellaway, 1994). This silent period has been seen to lengthen as fatigue develops (Taylor & Gandevia, 2001; Zghal et al., 2015) and any value of MVC does not seem to affect the duration of the silent period (Taylor et al., 1997). Zghal et al. (2015) had 23 sedentary male subjects randomly assigned to a control or a training group. The control acted as a sedentary control while the training group performed an 8-week low-force strength training program aimed at developing muscular endurance. The vastus lateralis, vastus medialis, and rectus femoris were stimulated for assessment via TMS at random intensities between 50-70% of machine stimulator output during a 20% MVC of knee extension force before and after an isometric task at 15% MVC until exhaustion. The authors reported that there was an increase in the silent period in the three muscles following fatigue.

Several studies have shown a decrease in MEP amplitude with a passive muscle following fatigue (Brasil-Neto et al., 1993; Kotan et al., 2015; Samii, Wassermann, Ikoma, Mercuri, & Hallett, 1996). This effect is called post-exercise depression and has been seen in resting muscles (Brasil-Neto et al., 1993). Brasil-Neto et al. (1993) had six subjects hold a weight in their dominant hand and perform wrist curls while assessing the MEP on the flexor carpi radialis with the results showing a decrease in MEP after fatigue. Kotan et al. (2015) had ten volunteers experience three different interventions: Voluntary contraction for 10 minutes at 10% MVC, tetanic electrical stimulation of the medium nerve in the wrist for 10 minutes at 10%, and electrical stimulation for 10 minutes at 90% intensity. The MEP showed a decrease following electrical stimulation and voluntary contraction but not solely with electrical stimulation without muscle contraction.

MEPs amplitude have been shown to increase immediately after the cessation of activity but then decrease during recovery (Ljubisavljević et al., 1996; Perretti et al., 2004). Perretti et al. (2004) had 41 patients with multiple sclerosis and 13 control subjects perform repetitive
contractions of the thenar muscle for 30 seconds at half of their MVC followed by a thirty second rest until considered fatigued, which was when the subject could not maintain half MVC for the 30 seconds. After each bout of contractions, MEPs were recorded and after fatigue set in, multiple MEPs were recorded during the first 30 seconds. There was an increase in MEP immediately after exercise, but it decreased when fatigue set in for both the patients and subjects. Fulton et al. (2002) examined post-exercise changes in MEP in five elite rowers and six non-rowers following a light exercise protocol and an intense exercise protocol. Muscles tested included the left and right erector spinae and first dorsal interosseous. The results showed an increase in MEP at two minutes when compared to baseline and a decrease at four to sixteen minutes for elite rowers in both exercise intensities. This effect of fatigue on MEP size has been shown to last four about 2 minutes (Samii et al., 1996). It appears that the motor cortex is hypersensitive to stimulation during exercise and then goes into a hyposensitive state while recovering from exercise. What has not been studied is the MEP of an active muscle after fatigue and how an activated fatigued muscle affects the MEP.

When stimulating active muscles, the MEP increases in size with isometric contractions, but the change in size will vary depending on the stimulated muscle. The MEP from the biceps brachii has been shown to continue to increase with increasing strengths of contraction until around 50-75% MVC (Taylor et al., 1997). Taylor et al (1997) had subjects perform voluntary contractions of the biceps brachii at 0, 5%, 10%, 25%, 50%, and 75% of MVC while applying TMS to the biceps brachii ranges from 20% below and 60% above threshold. The corticospinal neurons and the motoneurons increase in activity during voluntary contractions (Taylor & Gandevia, 2001; J. L. Taylor et al., 1997). It is currently unknown why a muscle contraction increases MEP amplitude and why there is a limit on the cap of MEP growth in relation to MVC. One theory is that some muscles are near their motor unit threshold at a lower MVC while others
are farther away from their threshold and can increase MEP with a raised MVC (Taylor et al., 1997).

Summary

The GH kinematics is affected by the rotator cuff. If the rotator cuff has any alterations in activation, this could cause changes in the kinematics of the humerus. These changes could increase the risk of injury in an individual. One change that could occur in GH joint kinematics could be from the fatigue of an individual muscle, a group of muscles, or the coordination of the muscle from the motor cortex. TMS can be used to study the influence of the motor cortex on the fatigue on an individual muscle. With the TMS, it is possible to look at the latency for muscle activation and the size of cortical activation with the MEP. This study aims to understand how fatigue of the infraspinatus can affect the latency from motor cortex stimulation and size of the MEP.
Chapter III

Methods and procedures

Introduction

This study was designed to investigate the hypothesis that latency, peak-to-peak duration and magnitude of MEP of the infraspinatus would increase after fatigue when compared to pre-fatigue conditions. Fatigue was achieved by asking subjects to perform multiple repetitions of external rotation of the humerus while using a Thera-Band (Akron, OH, USA) as resistance. A handheld dynamometer (Microfet2, Hoggan, UT, USA) was utilized to determine if fatigue was successfully induced, defined as a decrease of at least 25% of the initial force generated. The motor cortex was stimulated with transcranial magnetic stimulation (TMS), and electromyography (EMG) data was collected using surface electrodes on the right infraspinatus.

Description of Study Population

Eleven male and seven female subjects participated in this study and were recruited from the student body at Western Washington University. The average age was 22.5 ± 2.0 years with an average height of 175.8 ± 9.2 cm, and average mass of 73.4 ± 14.5 kg. Subjects were excluded from the study if they had a history of head trauma or shoulder pain during the past 6 months, shoulder surgery, any neck or upper extremity neuromuscular disorders (Appendix A). Participants were also screened for conditions that might place them in a higher risk for adverse effects of TMS (Appendix B). Subjects’ height and weight were recorded and previous shoulder injury or surgery was questioned and recorded (Appendix C).

Design of Study

A within-subject, repeated measures study was employed to examine the effect of fatigue of the infraspinatus on latency, peak-to-peak duration and magnitude of MEP. Subjects had their motor cortex stimulated via TMS before and after the infraspinatus fatigue.
Data Collection Procedures

**Instrumentation.** The procedure utilized surface EMG to measure muscle activation of the infraspinatus. TMS was used to stimulate the motor cortex of the brain in the contralateral hemisphere of the right shoulder. Force production during isometric external rotation was recorded using a handheld dynamometer.

**Surface electromyography.** The activation of the infraspinatus was monitored with surface EMG. The Noraxon TeleMyo desktop direct transmission EMG system (Noraxon, Scottsdale, AZ, USA) was used to monitor the amplitude of muscle activity. Sampling frequency was set to 1500Hz with a gain of 500 and CMRR > 100dB. All EMG data was smoothed using a root mean square (RMS) technique. Prior to placing the electrodes on the subjects, the skin was shaved and cleaned with alcohol wipes to reduce interfering noise. Two disposable Noraxon dual electrode self-adhesive Ag/AgCl surface electrodes were placed two cm apart on the muscle belly of the infraspinatus muscle parallel to muscle fiber orientation and approximately three cm inferior to the spine of the scapula (Ngomo, Mercier, & Roy, 2013). The muscle belly was palpated using submaximal isometric contraction, holding the humerus in external rotation while the forearm was flexed at 90°. One set of surface electrodes was for the Noraxon EMG system, the other was for the Brainsight 2 TMS mapping software (Montreal, Quebec). The maximum voluntary contraction (MVC) was measured by having the subject push into external rotation with 90° elbow flexion and no shoulder abduction with resistance at the distal forearm, close to the wrist, for five seconds (Wikholm & Bohannon, 1991).

**Transcranial magnetic stimulation.** Subjects were placed in a customizable chair with a padded headrest behind their head and another head support to the right side of their head (Figure 1). Mapping for TMS was completed using Brainsight 2 software. A headband with three
retroreflective markers was placed on the forehead to help set up a local coordinate system for tracking of head movement. Bony landmarks were then digitized using a pointer with three retroreflective makers for calibration of the local coordinate system. The bony landmarks were as follows: left preauricular, right preauricular, nasion and the lateral side of the right orbit (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003) The mapping of the brain to find optimal activation of the infraspinatus proceeded as follows: The C1 electrode of the International 1010 system was located by measuring halfway from the nasion to the occipital protuberance to find the vertex, and 40% of the measurement from the left preauricular to the right preauricular going through the vertex, up from the left preauricular (Oostenveld & Praamstra, 2001). Scalp locations were defined by using a 5-cm x 5-cm grid centered on C1 were digitized at 1 cm increments (Figure 3a). A Magstim BiStim² (Spring Gardens, Whitland, Carmathenshire, UK) using a figure-of-eight shaped coil was then used to stimulate each digitization point. The coil was angled at approximately 45° angle from posterior to anterior in order to obtain a current flow across the central sulcus and excite the neurons of the motor cortex. The coil was also held at an angle approximately tangent with respect to the scalp. Because the position of the shoulder influences the cortical excitability of the infraspinatus (Lin, Christie, & Karduna, 2015), the subject held their arm at 45° of scapular abduction with 8-12% MVC (Figure 3b). Stimulations started at 50% of maximum stimulator output and if there was an insufficient amplitude in the MEP, the stimulator output was increased by 5% (e.g. 50% to 55%) and the digitized grid was stimulated until a discernable MEP was found. The point with the largest MEP was then chosen for a smaller 2.5 cm x 2.5 cm grid to be digitized at 0.5 cm increments around that point to increase the precision for maximum stimulation. The new grid was then stimulated to find the most precise location for maximum MEP. Once the site was found with the highest excitability of the infraspinatus, the coil was then fixed in place to maintain optimal positioning. The strength of stimulator output was decreased 5% every 6 trials until a detectable MEP was shown for 50% of
the 6 stimulations, all while holding 8-12% MVC in order to determine active motor threshold (aMT). Then 120% of aMT was used for a total of 12 stimulations and recorded analysis (Triscott et al., 2008).

![Customizable chair with padded headrest and head support](image)

**Figure 1:** The customizable chair with padded headrest and head support

**Force production.** A Microfet 2 handheld dynamometer (Hoggan Scientific, Salt Lake City, Utah, USA) was used to measure force production in isometric shoulder external rotation. Subjects were instructed to hold a towel between their elbow and their torso in order to reduce humeral abduction during force production and fatiguing protocol. The elbow was placed at 90° flexion and the forearm was positioned at 45° of internal rotation, while the arm was semi-prone. The dynamometer was placed between the ulnar and radial styloid processes for each force measurement. Subjects were given a countdown before force production, and then externally rotated their arm with maximal effort for five seconds. This was repeated two more times and the highest force production was used for a benchmark of fatigue (Figure 2).
Measurement techniques and procedures. Upon signing up for the study, subjects were sent a copy of the eligibility questionnaire to review (Appendix A). If eligible, a time was scheduled for the subject to partake in the study. During the data collection, subjects were asked to review the informed consent form and questionnaire. They were then offered an opportunity to ask questions. Once all questions were answered, subjects were asked to sign the consent form and fill out the questionnaire.

After consent was given, the subject was then instrumented with EMG electrodes on the right infraspinatus and calibration of the TMS tracking system followed. Before mapping of the infraspinatus, maximum force production during shoulder external rotation was recorded three times for five seconds. The handheld dynamometer was utilized to measure force and the highest force output was used for fatigue comparison. After mapping of the infraspinatus, stimulation of the infraspinatus was recorded for a total of 12 trials with 10 seconds between each trial and the fatigue protocol followed afterwards.
Figure 3a: The mapping procedure using Brainsight software and a 5 x 5 cm grid to digitize points on the head for later stimulation.

Figure 3b: The stimulation process while the subject held their arm out parallel to the floor.
In order to induce fatigue in the infraspinatus muscle, subjects stayed seated and a towel was placed between their right arm and their torso to prevent humeral abduction by holding the towel in place via adduction. The subject then took hold of a yellow TheraBand (Theraband, Akron, Ohio, USA) in the hand of their tested arm with the forearm in a semi-prone position. They then stretched the band via external rotation as much as they could then back to the starting position, in a cyclic manner fatiguing the infraspinatus (Figure 4). Once subjects could not properly execute repetitions, force output via dynamometer was measured again after a bout of external rotation motion. If the force generated did not decrease by 25%, the subject continued the fatiguing protocol until the desired level of fatigue was reached. After fatigue was induced, 12 post-fatigue TMS stimulations were recorded.

Figure 4: The fatigue protocol of stretching a band with external rotation as a researcher holds the other end
Data processing

Motor evoked potentials were assessed from averages of ten full-wave EMG recordings synchronized to the time of the TMS stimulation. The data was retrieved using the MR3.6 (Noraxon, Scottsdale, AZ USA) software and Microsoft Excel (Redmond, Washington, USA) was then used to interpret the results. Peak-to-peak MEP duration was calculated by examining the time duration between the minima and maxima of the MEP. Muscle activation latency was measured by the amount of time displaced between stimulation and the onset of muscle activation of the MEP. MEP amplitude was calculated by the amount of difference in voltage between the minima and maxima of MEP.

Data Analysis

For this analysis the independent variable was condition (pre- and post-fatigue) and the dependent variables were the MEP amplitude, peak-to-peak duration, and the activation latency. All data analysis was performed using SPSS software version 22 (IBM North America, New York, NY). Data analysis of latency and amplitude of MEP of the infraspinatus was performed using a paired t-test, comparing the pre-fatigue and post-fatigue data. Alpha level was set to 0.017 (Bonferroni correction) for all analyses.
Chapter IV

Results and Discussion

Introduction

This study investigated the effect of fatigue on the motor evoked potential (MEP) of the infraspinatus muscle in healthy subjects. The independent variable is the testing condition (pre- and post-fatigue). While the dependent variables were MEP Amplitude, peak-to-peak duration, and muscle activation latency (Figure 5). Electromyography (EMG) was averaged between 12 stimulations. A paired t-test was used to compare the EMG signal of pre-fatigue to post-fatigue of the infraspinatus.

Results

Time to fatigue between subjects ranged from 34 seconds to 300 seconds (mean = 95 ± 68 seconds). The paired t-test revealed that peak-to-peak duration significantly increased in a fatigued state (p = 0.005) (Table 1). No significant difference was found in the MEP amplitude, and muscle activation latency (p > 0.05). There was a general decrease in MEP amplitude during post-fatigue, but this was not significant.

<table>
<thead>
<tr>
<th></th>
<th>Peak-to-Peak Duration (ms)</th>
<th>MEP Amplitude (uV)</th>
<th>Muscle Activation Latency (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-fatigue</td>
<td>4.5 ± 1.0</td>
<td>369.5 ± 481</td>
<td>14.0 ± 1.5</td>
</tr>
<tr>
<td>Post Fatigue</td>
<td>5.9 ± 1.6</td>
<td>277.2 ± 293</td>
<td>13.9 ± 1.5</td>
</tr>
</tbody>
</table>

Table 1: Mean and standard deviations

**Peak-to-peak duration.** Fatigue was found to have a significant effect on peak-to-peak MEP duration (p = 0.0005). Before fatigue, the average duration was 4.5 ms with an increase to 5.9 ms of duration after fatigue (Figure 6).
Figure 5: A sample of an averaged MEP from a single subject

Figure 6. A graphical comparison of the average peak-to-peak duration pre-fatigue and post-fatigue protocol. * $p < 0.05$
**MEP Amplitude.** There was a noticeable decrease in MEP amplitude in most subjects, but, this is not significant \( (p = 0.162) \). Average amplitude before fatigue was 381 mv followed by 269 mv after fatigue (Figure 7).

![MEP Amplitude Graph](image)

**Figure 7.** A graphical comparison of the MEP amplitude pre-fatigue and post-fatigue protocol.

**Muscle Activation Latency.** There is no statistically significant decrease in activation latency \( (p = 0.60) \), but the average did decrease by 0.1 ms this is a decrease of less than 1%. Therefore, it seems to be both non-significant and inconsequential, with an initial measurement of 14.0 ms pre-fatigue to 13.9 ms post-fatigue (Figure 8).
The purpose of this study was to examine the effects of fatigue on the MEP of the infraspinatus muscle compared to a non-fatigued state in healthy subjects. Specifically, this study examined muscle activation latency, peak-to-peak duration and amplitude. The hypothesis that all three variables would statistically increase due to fatigue was only supported with peak-to-peak duration, so, it was not supported. The amplitude of the MEP did show a trend of decreasing, but this result was non-significant.

There was a significant change in peak-to-peak duration in this study. This could be from a slower conduction velocity of fatigued muscles (Bigland-Ritchie, Johansson, Lippold, & Woods, 1983), however, it is uncertain whether this increase affects muscle activation or the electromechanical delay. Electromechanical delay is the time difference between the onset of
muscle electrical activation and the force production with the targeted muscle (Cavanagh & Komi, 1979). So far, there are no papers examining the electromechanical delay of the infraspinatus with TMS or electrical stimulation. Fuglevand et al. (1993) found similar findings with peripheral nerve stimulations of the first dorsal interosseous, where following a fatiguing exercise the peak-to-peak duration increased. There could also be the effects of changing to slower motor units with alterations in recruitment patterns due to fatigue (Thayer et al., 2000) and cause the stimulation to occur over a greater period of time.

When considering the results for MEP amplitude, the current study does not follow previous research into post-exercise depression, where the MEP shows a decrease in amplitude after a fatiguing exercise (Brasil-Neto et al., 1993). Most research with post-exercise depression examines the MEP within a resting muscle (Brasil-Neto et al., 1993; Kotan, Kojima, Miyaguchi, Sugawara, & Onishi, 2015; Liepert, Kotterba, Tegenthoff, & Malin, 1996; Samii, Wassermann, Ikoma, Mercuri, & Hallett, 1996) and the depression reflects the central fatigue of the motor cortex. During muscle fatigue, there is an increase in recruited motor units in order to sustain force production, and this is reflected with an increase in %MVC. Research has shown that muscle activation level does have an effect on MEP, in that the MEP will increase in amplitude with an increase in muscle activation (Taylor, Allen, Butler, & Gandevia, 1997) and that an active fatigued muscle would also exhibit an increase in MEP amplitude. Eichelberger and Bilodeau (2007) found the effects of central fatigue at the first dorsal interosseous (FDI) differed at 30% MVC when compared to 45%, 60% and 75% MVC, showing that less intense contractions might elicit a greater effect of central fatigue. Although this study uses the infraspinatus, the infraspinatus has not been tested on MEP size compared to %MVC, following fatigue, the infraspinatus should show an increase in the %MVC while holding the arm out when compared to pre-fatigue. In this current experiment, results from the post-fatigue MEP might reflect an increased %MVC for infraspinatus activation and if the infraspinatus follows the same
trend as the FDI and the biceps brachii discussed in previous studies, then the MEP was expected to have an increased amplitude during the fatigued state. Some subjects showed both increases and decreases in MEP amplitude following fatigue. This could be due to subjects holding their arm out for an extended period of time, possibly causing excessive fatigue and either enhancing the MEP amplitude or post exercise depression. Holding the arm horizontally could be canceling out the potential decrease in MEP amplitude. The deltoid might also be compensating with an increase in force production to hold the arm horizontally and by doing so, there may be a decrease in the activation of the infraspinatus.

This study did not show any significant changes in muscle activation latency. Changes in activation latency might influence the performance of the infraspinatus. Alterations in latency could have had the potential to place the infraspinatus out of sync with the other shoulder musculature by activation prematurely or lagging during synchronized activations. Fulton et al. (2002) found that elite rowers had an increase in latency of the erector spinae after light exercise, but not intense exercise. The change in latency could be due to different recruitment patterns in response to the intensity of exercise. It has been reported that chronic aerobic training can decrease the proportion of fast fatigable motor units to more non-fatigable motor units with slower transmission speeds (Thayer et al. 2000). Parkinson’s patients have shown lower values in muscle activation latency of the abductor digiti minimi of 8.1 ms when compared to a control group of 9.4 ms. (Kandler et al., 1990). These latency values are lower than what is found with the infraspinatus (14.0 ms) in the current research. The current research did not focus on physical activity training background and this may affect the recruitment pattern of motor units during fatigue. The repetitive maximal external rotations in the current study might be more similar to the intense exercise, due to stretching the TheraBand as much as they could, which did not show a change in latency in the rowers.
There are different key limitations that affect this study. The fatigue protocol consisted of repetitive and rapid contractions of the infraspinatus and this possibly resulted in more peripheral fatigue than central. It has been shown that repetitive concentric extension and flexion of the right quadriceps resulted in a decrease in muscle activation from electrical stimulation of the femoral nerve showing peripheral fatigue of the muscles (Froyd, Millet, & Noakes, 2013). A better way to assess central fatigue might have been to have an isometric contraction until the desired decrease in force reduction occurred. Long continuous bouts of contraction have been seen to have a greater effect on central fatigue (Taylor & Gandevia, 2001). The non-significant decrease in MEP amplitude may have been due to the lack of a central-fatigue focused exercise. Another limitation is that training status was not controlled for and training status has been shown to affect resistance, amplitude of central fatigue and rate of recovery (Enoka & Duchateau, 2008; Gandevia, 2001; Zghal et al., 2015). Subjects who are endurance trained have an increased tolerance to central fatigue (Zghal et al., 2015). The training focus or history of exercise was not controlled for this study and may have influenced the results.

Summary

Infraspinatus fatigue slightly alters the behavior of the MEP. Peak-to-peak duration significantly increased, but this might not have an overall effect on the infraspinatus. Most literature reported a post exercise depression of MEP following fatigue, but that was not found in this study and an increase in MEP amplitude was not found either. Muscle activation latency did not show any variability after the infraspinatus was exposed to the fatiguing protocol. Only one of the three hypotheses were supported in showing an increase in value.
Chapter V

Summary

This study examined the effects of fatigue on the motor evoked potential (MEP) of the infraspinatus. Subjects had transcranial magnetic stimulation (TMS) performed over the motor cortex, focusing on infraspinatus stimulation. The MEPs were recorded before and after a fatigue protocol consisting of resisted humeral external rotation while the elbow was on the side of the torso. The result of the current study showed that there was a significant increase in peak-to-peak duration following fatigue. Muscle activation latency and MEP amplitude did not show any significant changes following fatigue.

Conclusion

Fatigue of the infraspinatus significantly affected peak-to-peak duration with an increase in time during the MEP. This phenomenon might influence muscular performance if there is an effect on the electromechanical delay, but more research is needed to elucidate whether force production is altered. There was no effect on muscle activation latency and MEP amplitude following fatigue.

Recommendations

Future Research. This study identified an alteration in peak-to-peak duration after fatiguing a humeral stabilizing muscle. Further research is necessary to see if there are similar findings with subjects that have shoulder disorders. Additional research could change the fatigue protocol in order to examine different affects. Future research should investigate if the type of training affects the fatigued state of the MEP.


*Journal of Athletic Training,* 46(4), 349–357.


doi:10.1007/s00421-015-3123-y
CONSENT FORM

Purpose and Benefit:
The purpose of this experiment is to examine the brain processes associated with sensorimotor coordi- nation. The results of this study will advance our understanding of how the brain interacts with fatigued muscles. This research may lead to a greater understanding and treatment of movement disorders.

I UNDERSTAND THAT:
1) This experiment will involve filling out a screening questionnaire to determine eligibility for transcranial magnetic stimulation, a hand preference questionnaire, and a shoulder fatigue exercise. My participation in the experimental procedure will involve approximately 60 minutes.

2) Transcranial Magnetic Stimulation is a method for producing an electric current in a small part of the brain. During this procedure, a current passes through a copper coil that is wound inside a plastic casing and held over the participant’s head. The current in the coil produces a magnetic field, which passes safely through the scalp and causes electrical activity in brain tissue. The stimulation will be applied to the primary motor cortex of the brain during period of arm elevation.

Electrodes will measure the effect of the transcranial magnetic stimulation on the muscles of my right shoulder. The electrodes measure activity in the shoulder muscle and do not introduce electricity into the body.

3) Transcranial magnetic stimulation (TMS) of the brain has been reported to be a safe, non-invasive tool for investigating the link between the brain and muscles. There may, however, be some risks from being in this study. Common side effects and adverse health problems associated with TMS include, but may not be limited to:

- Slight discomfort, like a mild electrical shock, when the magnetic stimulation is applied
- Headache
- Neck ache
- Scalp discomfort at the site of stimulation
- Tingling, spasms or twitching of facial muscles
- Lightheadedness
- Possible increase or reduction immunity
- Slight skin irritation from the gel and adhesive tape used to apply the recording electrodes

Also, the long term effects of exposure to the strong electromagnetic field remain unknown, although research over the past two decades has produced no evidence for adverse effects.

On rare occasions, magnetic stimulation of the brain at a high frequency has been observed to induce epileptic seizures. Similar results, however, have not been found with the single pulse paradigm used in this study. Single pulse TMS has been used in a large number of participants with only a single reported case of seizure. If I am predisposed to seizures, I will not be allowed to participate.

4) My participation is voluntary; I may choose to stop the experiment and withdraw from participation at any
time without penalty. If I feel nervous, nauseous or light headed, I will tell the experimenter, and I will be able to take a break, or stop the experiment.

5) Sometimes participants experience headaches or local muscle pain due to muscle twitching. These usually go away on their own, or with non-prescription medication.

6) The risks of TMS to unborn fetuses are unknown. Because of this, if I am a female, I have been screened and asked if I may be pregnant. If there is a possibility that I may be pregnant, I cannot participate.

7) If I suspect that I may have any metal in my head, for example medical implants (e.g. clips, retainers, pacemakers, or pumps), bullet fragments, or metal fragments in the eye due to welding, I cannot participate.

8) All information is confidential. My signed consent form and questionnaires will be kept in a secured cabinet separate from the brain recordings and movement data. My name will not be associated with any of my data at any time.

9) My signature on the Photograph & Video release form hereby grant permission to the rights of my image, likeness and sound of my voice as recorded on audio or video tape without payment or any consideration. I also understand that this material may be used in diverse educational setting within an unrestricted geographic area.

10) My signature on this form does not waive my legal rights of protection.

11) This experiment is conducted under the supervision of Dr. Jun San Juan (Health and Human Development) and Dr. Kelly Jantzen (Psychology). Any questions that you have about the experiment or your participation may be directed to Dr. Jun San Juan at (360) 650-2336 or Dr. Kelly Jantzen at (360) 650-4046.

If you have any questions about your participation or your rights as a research participant, you can contact Janai Symons, Research Compliance Officer, Janai.symons@wwu.edu and (360) 650-3082.

If during or after participation in this study you suffer from any adverse effects, such as those listed in #3 above, as a result of participation, please notify Dr. Jun San Juan (360-650-2336; jun.sanjuan@wwu.edu), Dr. Kelly Jantzen (360 650-4046; kelly.jantzen@wwu.edu) or contact Janai Symons, Research Compliance Officer, Janai.symons@wwu.edu and (360) 650-3082.

I have read the above description, am at least 18 years of age, and agree to participate in this study.

Participant Signature __________________________ Date __________________________

Participant’s PRINTED NAME ____________________________________________

NOTE: Please sign both copies of the form and retain one copy for your records.
Appendix B:

Transcranial Magnetic Stimulation Screening Questionnaire
NAME OF PARTICIPANT................................................................. Sex:  M  F

Handedness (circle one):   L     R     Both

Date of Birth: (MM/DD/YYYY) ..............................................................

Have you participated in a previous TMS study at WWU?   Y    N

If yes, when: (MM/DD/YYYY) ..............................................................

Transcranial Magnetic Stimulation (TMS) is a method for producing an electric current in a small part of the brain. During TMS, a current passes through a copper coil that is wound inside a plastic casing and held over the participant’s head. The current in the coil produces a magnetic field, which passes safely through the scalp and causes electrical activity in brain tissue.

Before receiving TMS, please read the questions below carefully and provide answers. For a small number of individuals, TMS may carry an increased risk of causing a seizure. The purpose of these questions is to make sure that you are not such a person. You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive. The information you provide will be treated as strictly confidential and will be held in secure conditions.

If you are unsure of the answer to any of the questions, please ask the person who gave you this form, your physician, or your parents for clarification as to your medical history.
1. Do you have epilepsy or have you ever had a convulsion or a seizure?

2. Do any of your close relatives have epilepsy?

3. Have you ever fainted? (syncope)
   If YES, please describe the occasion(s) on the next page.

4. Have you ever had a head trauma that was diagnosed as a concussion or was associated with loss of consciousness?

5. Do you have any hearing problems or ringing in your ears?

6. Do you have cochlear implants?

7. Are you pregnant or is there any chance that you might be?

8. Have you ever had cranial (skull) surgery?

9. Do you have metal in the brain, skull or elsewhere in your body (e.g., splinters, fragments, clips, etc.)? If YES, specify the type of metal on the next page.

10. Do you have an implanted neurostimulator (e.g., Deep brain stimulation, Vagus Nerve Stimulation)?

11. Do you have a cardiac pacemaker or intracardiac lines?

12. Do you have a medication infusion device?

13. Have you ever suffered injury to your brain not limited to: infection, lesion, stroke, illness, tumor, or any other brain condition?

14. Have you ever had, or currently have, any of: anxiety, depression, or any other mental health issues (with or without treatment?)

15. Have you suffered severe or recent heart disease

16. Are any of the following true: (a) you have drunk any alcohol in the past 24 hours; (b) you typically drink four, or more, alcoholic drinks in one day; (c) you are alcohol dependent; (d) you are undergoing withdrawal from alcohol; (e) you are undergoing withdrawal from barbiturates, benzodiazepines, meprobamate, or chloral hydrate.

17. Do you have a sleep deficit in the last 24 hours? (We define a sleep deficit as two hours less than your usual amount of sleep, or less sleep. If you typically sleep 8 hours, for instance, a "sleep deficit" would be 6 hours sleep or less.)

18. Are you taking any of the medications or recreational drugs listed on the next pages, either as prescribed, or frequently, or any use in the previous week?

19. Have you ever had an EEG for a medical condition or a suspected medical condition?

20. Do you suffer from frequent or severe headaches?

21. Did you ever undergo TMS in the past? If YES describe any problems on the next page.

22. Did you ever undergo MRI in the past? If YES, describe any problems on the next page.

I have read and understood the questions above and have answered them correctly.

Signed:…………………………… Date:…………………………

In the presence of:…………………………. (Name) ……………………………. (Signature)
List of drugs related to TMS participation – Grouped by condition they treat or mode of action.

<table>
<thead>
<tr>
<th>Drug Name</th>
<th>Commercial/Street Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANTIDEPRESSANTS</strong></td>
<td></td>
</tr>
<tr>
<td>imipramine</td>
<td>Tofrinil</td>
</tr>
<tr>
<td>amitriptyline</td>
<td>Duo-Vil, Etrafon, Triavil, Triptafen</td>
</tr>
<tr>
<td>doxepin</td>
<td>Sinequan, Deptran, Adapin, Silenor, Zonalon, Prudoxin</td>
</tr>
<tr>
<td>nortriptyline</td>
<td>Sensoval, Aventyl, Pamelor, Norpress, Allegron, Noritren, Nortrilen</td>
</tr>
<tr>
<td>maprotiline</td>
<td>Ludiomil, Deprilept Psymion</td>
</tr>
<tr>
<td><strong>ANTIPSYCHOTICS</strong></td>
<td></td>
</tr>
<tr>
<td>chlorpromazine</td>
<td>Thorazine, Largactil</td>
</tr>
<tr>
<td>clozapine</td>
<td>Clozaril, FazaClo, Versacloz</td>
</tr>
<tr>
<td><strong>ANTIVIRAL</strong></td>
<td></td>
</tr>
<tr>
<td>foscarnet</td>
<td>Foscavir</td>
</tr>
<tr>
<td>ganciclovir,</td>
<td>Cytovene, Cymeve, Vitasert</td>
</tr>
<tr>
<td>ritonavir,</td>
<td>Norvir</td>
</tr>
<tr>
<td><strong>STIMULANTS</strong></td>
<td></td>
</tr>
<tr>
<td>amphetamines</td>
<td>Adderall, Dexedrine, Dexacaps, ProCentra, Vyvanse</td>
</tr>
<tr>
<td>methamphetamine</td>
<td>Desoxyn, crystal meth, speed, ice</td>
</tr>
</tbody>
</table>
### ALPHABETICAL LIST OF DRUGS

<table>
<thead>
<tr>
<th>Drug</th>
<th>Category</th>
<th>Brand Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapin</td>
<td>gamma-hydroxybutyrate</td>
<td>Special K</td>
</tr>
<tr>
<td>Adderall</td>
<td>chlorpromazine</td>
<td>speed</td>
</tr>
<tr>
<td>Allegron</td>
<td>clozapine</td>
<td>Theo-24</td>
</tr>
<tr>
<td>Amitriptyline</td>
<td>Clozaril</td>
<td>imipramine</td>
</tr>
<tr>
<td>amphetamines</td>
<td>cocaine</td>
<td>Ketalar</td>
</tr>
<tr>
<td>angel dust</td>
<td>coke</td>
<td>Ketamine, Ketaset, &quot;Special K,&quot;</td>
</tr>
<tr>
<td>Aventyl</td>
<td>crack</td>
<td>Ketanest, Ketaset, Ketalar</td>
</tr>
<tr>
<td>blow</td>
<td>crystal meth</td>
<td>maprotiline</td>
</tr>
<tr>
<td>chlorpromazine</td>
<td>Deprilept Psymion</td>
<td>methamphetamine</td>
</tr>
<tr>
<td>clozapine</td>
<td>Deprilept Psymion</td>
<td>Noritren</td>
</tr>
<tr>
<td>Clozaril</td>
<td>Deprilept Psymion</td>
<td>Norpress</td>
</tr>
<tr>
<td>cocaine</td>
<td>Desoxyn</td>
<td>Nortrilen</td>
</tr>
<tr>
<td>coke</td>
<td>Dexedrine</td>
<td>nortriptyline</td>
</tr>
<tr>
<td>crack</td>
<td>Doxycycline</td>
<td>Norvir</td>
</tr>
<tr>
<td>crystal meth</td>
<td>Duoxin</td>
<td>Palmol</td>
</tr>
<tr>
<td>Cymevene</td>
<td>Dextroamphetamine</td>
<td>PCP</td>
</tr>
<tr>
<td>Cytovene</td>
<td>Dexedrine</td>
<td>phencyclidine</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>Duo-Vil</td>
<td>ProCentra</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>dust</td>
<td>Rivotril</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>ecstasy</td>
<td>Rivotril</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>Elioxphylin</td>
<td>Quibron-T</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>Etrafon</td>
<td>ritonavir,</td>
</tr>
<tr>
<td>Deprilept Psymion</td>
<td>FazaClo</td>
<td>rock</td>
</tr>
<tr>
<td>fosfomycin</td>
<td>fosfomycin</td>
<td>Sensoval</td>
</tr>
<tr>
<td>Foscavir</td>
<td>fosfomycin</td>
<td>Silenor</td>
</tr>
<tr>
<td>Foscavir</td>
<td>fosfomycin</td>
<td>Sinequan</td>
</tr>
</tbody>
</table>

### HALLUCINOGENS

<table>
<thead>
<tr>
<th>Drug</th>
<th>Category</th>
<th>Brand Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>cocaine</td>
<td>HALLUCINOGENS</td>
<td>&quot;coke,&quot; &quot;blow,&quot; &quot;dust,&quot; &quot;rock,&quot; &quot;crack&quot;</td>
</tr>
<tr>
<td>MDMA</td>
<td>HALLUCINOGENS</td>
<td>ecstasy</td>
</tr>
<tr>
<td>phenylcyclidine</td>
<td>HALLUCINOGENS</td>
<td>PCP, angel dust</td>
</tr>
<tr>
<td>ketamine,</td>
<td>HALLUCINOGENS</td>
<td>Ketanest, Ketaset, Ketalar, &quot;Special K,&quot;</td>
</tr>
</tbody>
</table>

### DEPRESSANTS

<table>
<thead>
<tr>
<th>Drug</th>
<th>Category</th>
<th>Brand Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>gamma-hydroxybutyrate</td>
<td>DEPRESSANTS</td>
<td>GHB</td>
</tr>
</tbody>
</table>

### BRONCHODILATORS

<table>
<thead>
<tr>
<th>Drug</th>
<th>Category</th>
<th>Brand Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>theophylline</td>
<td>BRONCHODILATORS</td>
<td>Theolair, Theo-24, Uniphyl, Elixophylin, Quibron-T</td>
</tr>
</tbody>
</table>

---

51
Appendix C:

Protocol Checklist

<table>
<thead>
<tr>
<th>Subject ID: FTMS_</th>
<th>Date: / /</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed consent signed:</td>
<td>YES / NO</td>
</tr>
<tr>
<td>TMS Safety Protocol consent signed:</td>
<td>YES / NO</td>
</tr>
<tr>
<td>Informed consent understood, questions answered:</td>
<td>YES / NO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Height:</th>
<th>Age:</th>
<th>Weight:</th>
<th>Gender:</th>
<th>Dominant hand: R / L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Does subject have a history of right shoulder injury or surgery? YES* / NO

*if yes, subject must be excluded from the study

Discuss protocol: We will find the maximum output and MVC of the infraspinatus using external rotation of the arm with a handheld dynamometer

1. We will Map the motor cortex to find the infraspinatus while the subject holds their arm at 45 degrees.
2. Collect data for pre-fatigued state
3. Fatigue protocol of externally rotating pulling a theraband
4. Collect data for post-fatigued state

Test protocol explained to subject: YES / NO

MVC performed: YES / NO

Instrumentation completed on right side:
- □ EMG for Noraxon
- □ EMG for Brainsight

<table>
<thead>
<tr>
<th>Force Output</th>
<th>Trial 1:</th>
<th>Trial 2:</th>
<th>Trial 3:</th>
<th>75%:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Head Measurements</th>
<th>Anterior Posterior:</th>
<th>Lateral:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Threshold: 120%:

Endurance Time:

<table>
<thead>
<tr>
<th>Pre-Fatigue</th>
<th>Post-Fatigue</th>
<th>Post-Fatigue (5min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>
Appendix D:

Photograph & Video Release Form

I hereby grant permission to the rights of my image, likeness and sound of my voice as recorded on audio or video tape without payment or any other consideration. I understand that my image may be edited, copied, exhibited, published or distributed and waive the right to inspect or approve the finished product wherein my likeness appears. Additionally, I waive any right to royalties or other compensation arising or related to the use of my image or recording. I also understand that this material may be used in diverse educational settings within an unrestricted geographic area.

Photographic, audio or video recordings may be used for the following purposes:

- conference presentations
- educational presentations or courses
- informational presentations
- on-line educational courses
- educational videos

By signing this release I understand this permission signifies that photographic or video recordings of me may be electronically displayed via the Internet or in the public educational setting.

I will be consulted about the use of the photographs or video recording for any purpose other than those listed above.

There is no time limit on the validity of this release nor is there any geographic limitation on where these materials may be distributed.

This release applies to photographic, audio or video recordings collected as part of the sessions listed on this document only.

By signing this form I acknowledge that I have completely read and fully understand the above release and agree to be bound thereby. I hereby release any and all claims against any person or organization utilizing this material for educational purposes.

Full Name___________________________________________________
Street Address/P.O. Box________________________________________
City________________________________________________________
Postal Code/Zip Code__________________________________________
Phone ___________________________ Fax _______________________
Email Address________________________________________________
Signature_________________________ Date________________________

If this release is obtained from a presenter under the age of 19, then the signature of that presenter’s parent or legal guardian is also required.

Parent’s Signature ______________________ Date____________________
Appendix E:

Raw Data

<table>
<thead>
<tr>
<th>Subject</th>
<th>MEP</th>
<th>Muscle Activation Latency</th>
<th>Peak-to-Peak Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-MEP (uv)</td>
<td>Post-MEP (uv)</td>
<td>Pre Latency (ms)</td>
</tr>
<tr>
<td>1</td>
<td>288.57</td>
<td>290.77</td>
<td>14.00</td>
</tr>
<tr>
<td>2</td>
<td>66.89</td>
<td>30.75</td>
<td>10.67</td>
</tr>
<tr>
<td>3</td>
<td>88.81</td>
<td>54.84</td>
<td>13.33</td>
</tr>
<tr>
<td>4</td>
<td>176.65</td>
<td>71.49</td>
<td>13.33</td>
</tr>
<tr>
<td>5</td>
<td>348.23</td>
<td>99.98</td>
<td>14.00</td>
</tr>
<tr>
<td>6</td>
<td>87.66</td>
<td>129.07</td>
<td>15.33</td>
</tr>
<tr>
<td>7</td>
<td>342.77</td>
<td>308.41</td>
<td>14.67</td>
</tr>
<tr>
<td>8</td>
<td>79.47</td>
<td>40.97</td>
<td>14.67</td>
</tr>
<tr>
<td>9</td>
<td>122.83</td>
<td>119.94</td>
<td>15.33</td>
</tr>
<tr>
<td>10</td>
<td>1955.97</td>
<td>1075.93</td>
<td>16.00</td>
</tr>
<tr>
<td>11</td>
<td>833.78</td>
<td>242.73</td>
<td>14.00</td>
</tr>
<tr>
<td>12</td>
<td>195.58</td>
<td>166.76</td>
<td>13.33</td>
</tr>
<tr>
<td>13</td>
<td>312.22</td>
<td>613.56</td>
<td>16.00</td>
</tr>
<tr>
<td>14</td>
<td>359.29</td>
<td>401.54</td>
<td>16.67</td>
</tr>
<tr>
<td>15</td>
<td>95.34</td>
<td>51.45</td>
<td>12.00</td>
</tr>
<tr>
<td>16</td>
<td>39.67</td>
<td>35.05</td>
<td>12.00</td>
</tr>
<tr>
<td>17</td>
<td>1088.81</td>
<td>855.78</td>
<td>13.33</td>
</tr>
<tr>
<td>18</td>
<td>167.67</td>
<td>261.88</td>
<td>14.00</td>
</tr>
</tbody>
</table>