CHANGE IN FINGER FORCE PRODUCTION AND MUSCLE ACTIVATION IN THE FOREARMS OF ROCK CLIMBERS DURING TREADWALL CLIMBING

by

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TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Rock climbing is a multi-faceted sport requiring finger flexor strength and endurance. Sustained isometric contractions lead to the build-up of metabolic byproducts that fatigue the finger flexors, however the effect of climbing ability on muscular fatigue is not fully understood. The purpose of the present study is to investigate the effects of rock climbing ability on time to fatigue (TTF), relative finger force production (REL FP), change in FP (ΔFP), and changes in muscle activity during bouts of climbing on a treadwall. Eight advanced (6 male, 2 female: 29.3±4.7 yrs, 69.1±6.9 kg, years experience: 11.1±5.2) and seven novice (5 male, 2 female: 21±2.3 yrs, 67.6±3.8 kg, years experience: 3.0±2.6) subjects participated. Subjects warmed-up on the treadwall and mounted force tranducer. Electromyographic (EMG) electrodes were placed over the *flexor digitorum superficialis* (FDS), *biceps brachii* and *triceps brachii* muscle to measure motor unit action potentials. Root mean square (RMS) and median frequency (MF) were analyzed from EMG data. Subjects performed a pre-exercise, 20-second maximal voluntary isometric contraction ($MVIC_{PRE}$) with the fingertips of the dominant hand (DH) and non-dominant hand (NDH). The climbing protocol consisted of climbing for 5-minute intervals. Subjects performed another MVIC after each interval. EMG and force data were recorded during MVICs. A total of six intervals were performed, or until failure. Group comparisons were made at the 5^{th} interval ($MVIC_{POST}$). Climbing ability and handedness were analyzed using a 2x2 mixed ANOVA with repeated measures (alpha level < 0.05). Significant group differences were observed for TTF, REL FP, and percent ΔFP and FDS ΔMF. Advanced climbers' average REL FP during $MVIC_{PRE}$ was 5.6±1.4 N/kg BW and 5.2±1.6 N/kg from the DH and NDH, respectively. Novice REL FP was 3.1±0.8 N/kg BW and 3.1±1.0 N/kg. Novices ΔFP decreased 30.8±16.0% and 24.9±18.6%, advanced climbers experienced no change. Advanced MF increased 4.8±25.9% and 7.7±18.8%, novice MF decreased 22.7 ± 6.5% and 12.6 ± 15.5%. In conclusion, advanced climbers demonstrated a resistance to climbing-specific fatigue during bouts of treadwall climbing.

CHAPTER ONE

INTRODUCTION

Rock Climbing Origins

The sport of rock climbing has undergone vast changes over the last one hundred years. Originating on the fringe of society, rock climbing has moved into mainstream culture and become more popular with recreationists and competitive athletes alike (Climbing Business Journal, 2015). Rock climbing, however, is a broad term describing several different sub disciplines within the same mountain-sport genre. It is important to clarify which sub-discipline is being discussed and the context in which it evolved over time.

The roots of modern rock climbing are planted in late 19th century European mountaineering, particularly from the area surrounding Chamonix, France (Mountaineers, 2010). Mountaineers implemented early aid climbing techniques to overcome difficult portions of a route that could not be climbed using strictly the hands and feet. In this aid climbing style, the leader would hammer metal pitons into the rock and attach them to nylon ladders for upward movement. Aid climbing came to America in the early 1900s where it was applied to the sheer cliffs of Yosemite National Park and other mountainous regions (Roper, 1998). By the 1970s, and with the advent of better protection equipment, climbers continued to push boundaries without relying on aid equipment. Lines that were previously aid climbed were now being ascended safely using strictly hands and feet. This new style became known as free climbing and is synonymous with modern day rock climbing. It required a new set of skills when compared to aid climbing, and, above all, a new level of athleticism (Taylor, 2010). This was the era in which modern rock climbing diverged from mountaineering and big wall aid climbing. While aid climbing is still frequently practiced to this day, free climbing and its variations have become the dominant forms of rock climbing around the world.

In this study, the term rock climbing will be derived from this meaning: using one's hands and feet for upward propulsion without the assistance of ladders or other aid equipment.

Development of Problem

Free climbing brought both new challenges and physiological demands to rock climbers. Unlike aid climbing, free climbing is dominated by isometric contractions of the finger flexors (Sheel, 2004). Forgoing aid ladders meant climbers relied more heavily on their musculature to keep them on the rock face, therefore free climbing required increased finger flexor strength and endurance. Rock climbers began to train more and, as standards progressed, so did the capacity of climber's forearms to resist fatigue and maintain intense contractions over prolonged periods of time.

While there have been studies on climbing-specific finger strength and endurance, little research has been devoted to investigating *in-vivo* fatigue of the digit flexors during bouts of rock climbing. Moreover, while physiological differences due to years of training have been noted in the literature, the way in which these adaptations manifest themselves during climbing is not fully understood.

Purpose Statement

The purpose of the present study is to evaluate the influence of rock climbing ability on finger force production, muscle activity and fatigue in the forearms of novice and advanced climbers during bouts of intermittent climbing on a treadwall.

Hypothesis

It is hypothesized that the advanced group will have a greater time to fatigue (TTF), mean force production relative to body weight (REL FP), a lesser change in force production (ΔFP), a lesser change in median frequency (ΔMF) and a lesser change in root mean square (ΔRMS) when compared to the novice group.

Ho: $TTF_{, Nov} = TTF_{, Adv}$	Ha: $TTF_{, Nov} < TTF_{, Adv}$
Ho: $REL\ FP_{, Nov} = REL\ FP_{, Adv}$	Ha: $REL\ FP_{, Nov} < REL\ FP_{, Adv}$
Ho: $\Delta FP_{, Nov} = \Delta FP_{, Adv}$	Ha: $\Delta FP_{, Nov} > \Delta FP_{, Adv}$
Ho: $\Delta MF_{, Nov} = \Delta MF_{, Adv}$	Ha: $\Delta MF_{, Nov} > \Delta MF_{, Adv}$
Ho: $\Delta RMS_{, Nov} = \Delta RMS_{, Adv}$	Ha: $\Delta RMS_{, Nov} > \Delta RMS_{, Adv}$

Limitations

- The results of this study are only applicable to individuals who primarily route climb.
- Movement of EMG electrodes may have occurred, resulting in skewed or non-results.

- Some cross talk may have been present due to the complexity of forearm musculature and usage of sEMG.
- Subjects had to become habituated to the treadwall system and mounted force plate within one session in the MSL.
- Daily fluctuations in physiology may have affected climbing overall performance.

Delimitations

- Restricted to adults age 21 to 39 in the Bozeman, MT area.
- Subjects must climb for 5 minutes without rest.
- Subjects must abstain from training within 24 hours of testing.
- Subjects must not consume caffeine within 6 hours of testing.
- Subjects must be fed within 3-4 hours of testing.
- Subjects limited to those with no serious injuries in the last 6 months.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

The Muscular System and Muscular Contractions

The muscular system of the human body generates movement, provides stability and allows humans to perform a vast array of exercises (Levangie et al., 2011). Muscles are excitable tissue that contract or relax with electrical stimuli. Concentric contraction occurs when the individual working unit of the muscle, the sarcomere, is stimulated by a motor neuron and shortens on either side of the midline. This action is compounded thousands of times within each muscle fiber, resulting in the overall shortening of the muscle. Muscles act on joints in a way that is similar to conventional levers: muscles originate on one side of the joint (hinge) and insert on the other. When a contraction occurs, the muscle fibers pull to widen or narrow the joint. The resultant action depends on the fiber's line of pull and its relationship to the joint's center of rotation.

These basic concepts have many physiological applications depending on the task. Muscle contractions due to shortening of the sarcomeres against an external force is known as a concentric contraction (Kenny et al., 2012). Muscles that are actively lengthened - that is, the sarcomeres are elongated while resisting an external force - is known as an eccentric contraction. Lastly, are isometric contractions which occur when the muscle is contracted against an unmoving object, such as a rock hold. The muscle fibers do not change length but muscular tension increases. During rock climbing, the finger flexors perform "continuous isometric contractions for upward propulsion" (Sheel, 2004). However, sustained intervals of isometric contraction lead to unique problems relating to fatigue.

Muscular Fatigue and Rock Climbing

Fatigue is defined as a decline in maximum contractile force or the inability to maintain a level of force production (Enoka et al., 1988). During a rock climbing ascent, the finger flexors, tendons and ligaments repeatedly undergo high levels of strain while maintaining isometric contractions on small holds. It has been suggested that the finger flexors contract and relax at a 13:1 ratio during an ascent (White & Olsen, 2010). These contractions slow blood flow to the forearm musculature, resulting in localized muscular fatigue (LMF) of the *flexor digitorum superficialis* (FDS) and surrounding musculature (Barnes, 1980). Localized muscular fatigue during climbing can be attributed to many causes, however there are two driving principals: blood occlusion to the working tissue and subsequent acidosis of the musculature due to the build-up of metabolic byproducts, particularly hydrogen ions (Green, 2004; Watts et al., 1996).

Blood occlusion during isometric contractions of the forearm musculature is a primary cause of LMF during rock climbing. During prolonged contractions, the veins, arterioles, and capillary beds of the working tissue are constricted and blood perfusion is reduced (Watts, 2004; Vigoroux and Quaine, 2006; Vigoroux et al., 2014). The degree to which blood is occluded is relative to the intensity of the contraction. Decreased blood flow reduces the amount of oxygen and nutrient delivery to the muscle. Buffering capacity and clearance rate of metabolic byproducts are also reduced. Greater blood flow, vasodilation and oxygenation capacity of the finger flexors between contractions has been observed for well-trained climbers when compared to novices (MacLeod et al., 2007, Fryer et al. 2014a, 2014b).

During exercise, working muscle tissue creates metabolic by-products such as hydrogen ions, lactate, carbon dioxide, ammonia, and urea (Kenny et al., 2012). The continual ebb and flow of blood to the finger flexors results in the accumulation of exercise metabolites, which may lead to forearm musculature acidosis. Acidosis of the musculature decreases cross-bridge strength and overall contraction strength. It has been noted that blood lactate levels can be elevated in climbers for upwards of 20 minutes post-climbing, associated with a 22% decrease in finger flexion strength (Watts et al., 1996). Colloquially known as “forearm pump,” the metabolic acidosis of the finger flexors is a primary factor in climbing fatigue and failure during a route (Hague & Hunter, 2006; Phillippe et al., 2012).

At all levels of experience, blood occlusion and muscular acidosis affect rock climbers. Understanding the underlying mechanisms of climbing-specific fatigue is an important step towards improving climbing performance for the future. Study of LMF in rock climbers could yield improvements in training protocols, changes in contraction-to-relaxation ratios and improve the overall enjoyment of the sport. Moreover, identifying indices of fatigue could benefit future studies focused on supplementation or be utilized during skill assessments. Considered to be “one of the most important yet least understood” aspects of climbing, the finger flexor’s ability to resist fatigue remains an important, unanswered question in rock climbing research (Fryer et al., 2014b).

Fatigue and EMG Analysis

Electromyography (EMG) is a means of measuring muscle activation via motor unit action potentials (MUAP, De Luca, 1997). Motor units originating in the spine use electrical signals to contract working muscle. Electromyography measures electrical differentials within the muscles, allowing researchers to determine when the muscle is effectively “on” or “off.” There are two types of electromyography: surface EMG (sEMG) and needle EMG. Surface electromyography utilizes electrodes placed on the skin to measure action potentials produced within the body. Needle EMG uses electronic needles placed within the muscle belly to measure the electrical activity directly. Use of needle EMG limits full range of motion, which is essential for climbing performance. The current study will utilize sEMG, as it allows for full range of motion during exercise. Moreover, because rock climbing is dominated by isometric contractions in the finger flexors, sEMG is well-suited for this application (DeLuca, 1997).

Raw EMG signal is a sinusoidal wave; however, many pieces of information can be extrapolated from this data. By evaluating the amplitude and frequency of the raw signal, it is possible to observe basic activation properties of the muscle. Methods of post-processes utilizing mathematical transformations can be applied to an EMG signals to gather further information. Two of which utilized in this study are root mean square (RMS) and median frequency (MF)

Root mean squared is a mathematical transformation that yields the average of a fluctuating electrical signal. When applied to EMG, it gives an estimated smoothed average of motor unit recruitment in the muscle for a given period of time (Cram et al., 2003). When the muscle is activated, the RMS will increase due to increased motor unit recruitment. During fatigued states however, an elevated RMS signal is also possible. This is due to the recruitment of additional motor units to meet the force necessary to complete a given task.

Another commonly utilized method for analyzing fatigue is mean power frequency and median power frequency (MF) (Phinyomark et al., 2012). First, a Fast Fourier Transformation must be employed to convert the raw EMG signal from a time-domain to a frequency-domain. The domain determines which variable is independently analyzed (i.e. the x-axis when graphed). The frequency-domain (also known as a power spectrum) indicates what frequencies comprised the initial EMG signal. In terms of physiology, the frequency-domain estimates what type of motor units are being recruited during a contraction. Easily-fatigable Type IIa/x motor units are typically associated with higher frequencies, while fatigue-resistant Type I motor units are associated with lower frequencies. (Cram et al., 2003).

Mean power frequency is the average frequency of the sum of the product of the EMG power spectrum divided by the total sum of the power spectrum (Oskoei & Hu, 2008, reported by Phinyomark et al., 2012). It is the average frequency of the motor units being recruited during a muscle contraction. Median power frequency, however, is the frequency in which the power spectrum is divided into two sections of equal amplitude. As muscle tissue fatigues, there is a shift from the high-frequency, Type IIa/x motor units to the lower-frequency, Type I motor units. Both mean frequency and MF can be utilized to assess muscle fatigue over time, however MF is more commonly used due to its robustness to extreme ranges of frequency (Merletti & Knaflitz, 1990).

Muscular fatigue during climbing has been shown to influence activation patterns of the primary finger flexors. Studies have been devoted to analyzing fatigue in climbers via sEMG (Watts et al., 2008, Quiane, 2003; Vigoroux & Quaine, 2006; Quaine & Vigoroux, 2004). Surface EMG was used to measure fatigue in climbers during continual submaximal contractions. During fatigued contractions, there was a shift towards lower frequencies and a reduction in the amplitude of high-frequency components in the overall EMG signal. While not entirely conclusive without corresponding force data, this is indicative of a fatigued muscle. The Type IIa/x motor units have been exhausted and the climber is relying on Type I motor units for force production. It should be noted that previous studies have utilized a handgrip dynamometer to test climbing strength (Vigoroux & Quaine, 2006; Limonta et al., 2015). Handgrip dynamometry has been shown to activate forearm muscles differently than actual rock climbing when assessed with EMG (Watts et al., 2008).

Limitations to EMG should also be noted. While it is effective for analyzing muscle activity, proper placement of the electrode is vital to receiving a true signal (Cram et al., 2003). The electrode must be placed directly over the belly of the muscle, as surrounding tissue (e.g. tendon, ligament, other musculature) can create noise. Moreover, the electrode must be placed with respect to the pennation angle of the musculature Subcutaneous fat may also skew results. Lastly, due to the nature of sEMG it cannot be used solely as a means of identifying fatigue. Force data must also be collected as the primary means of determining fatigue and further verified using sEMG.

Electromyography is an effective tool for analyzing muscle activation as well as verifying fatigue in skeletal muscle. The present study will utilize finger force production as well as sEMG to quantify pre- versus post-exercised states in rock climbers using a treadwall and mounted force plate. Finger force production will be the primary means of determining fatigue, while RMS and MF will be used to verify changes in motor unit recruitment and fiber type over time. Future studies may be devoted to determining larger trends in climbing-specific muscle activation or duration of contraction over time. To our knowledge, this is the first study of its kind to use these tools as a means of testing fatigue during rock climbing.

Conclusion

In summation, the nature of rock climbing presents unique challenges to its participants due to the repetitive forearm contractions that accompany an ascent. Acute fatigue of the forearm musculature is the primary cause of failure during an ascent, however advanced climbers appear to have some form of resistance to this fatigue. Previous studies have been dedicated to comparing trained versus untrained climbers in terms of finger force production and muscle activity, but differences in methodology persist. The purpose of the present study is to build upon previous literature by fatiguing participants during bouts of climbing on a treadwall system.

CHAPTER THREE

CHANGE IN FINGER FORCE PRODUCTION AND MUSCLE ACTIVATION IN THE FOREARMS OF CLIMBERS DURING TREADWALL CLIMBING

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

Author: Philip F. Ferrara III

Contributions: Primary investigator and developer of study methodology, primary processor and analyzer of data, and authored manuscript.

Co-Authors: John G. Seifert

Contributions: Dr. Seifert assisted with development of study methodology, assisted with data analysis, development of conclusions.

Co-Authors: Mary P. Miles

Contributions: Dr. Miles reviewed the study design and recommended changes; reviewed study results, analysis and conclusions; and the study proposal and final manuscript.

Co-Authors: James Becker

Contributions: Dr. Becker reviewed the study design and recommended changes; reviewed study results, analysis and conclusions; and the study proposal and final manuscript.

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Abstract

Rock climbing is a multi-faceted sport requiring finger flexor strength and endurance. Sustained isometric contractions lead to the build-up of metabolic byproducts that fatigue the finger flexors, however the effect of climbing ability on muscular fatigue is not fully understood. The purpose of the present study is to investigate the effects of rock climbing ability on time to fatigue (TTF), relative finger force production (REL FP), change in FP (ΔFP), and changes in muscle activity during bouts of climbing on a treadwall. Eight advanced (6 male, 2 female: 29.3±4.7 yrs, 69.1±6.9 kg, years experience: 11.1±5.2) and seven novice (5 male, 2 female: 21±2.3 yrs, 67.6±3.8 kg, years experience: 3.0±2.6) subjects participated. Subjects warmed-up on the treadwall and mounted force tranducer. Electromyographic (EMG) electrodes were placed over the *flexor digitorum superficialis* (FDS), *biceps brachii* and *triceps brachii* muscle to measure motor unit action potentials. Root mean square (RMS) and median frequency (MF) were analyzed from EMG data. Subjects performed a pre-exercise, 20-second maximal voluntary isometric contraction ($MVIC_{PRE}$) with the fingertips of the dominant hand (DH) and non-dominant hand (NDH). The climbing protocol consisted of climbing for 5-minute intervals. Subjects performed another MVIC after each interval. EMG and force data were recorded during MVICs. A total of six intervals were performed, or until failure. Group comparisons were made at the 5^{th} interval ($MVIC_{POST}$). Climbing ability and handedness were analyzed using a 2x2 mixed ANOVA with repeated measures (alpha level < 0.05). Significant group differences were observed for TTF, REL FP, and percent ΔFP and FDS ΔMF. Advanced climbers' average REL FP during $MVIC_{PRE}$ was 5.6±1.4 N/kg BW and 5.2±1.6 N/kg from the DH and NDH, respectively. Novice REL FP was 3.1±0.8 N/kg BW and 3.1±1.0 N/kg. Novices ΔFP decreased 30.8±16.0% and 24.9±18.6%, advanced climbers experienced no change. Advanced MF increased 4.8±25.9% and 7.7±18.8%, novice MF decreased 22.7 ± 6.5% and 12.6 ± 15.5%. In conclusion, advanced climbers demonstrated a resistance to climbing-specific fatigue during bouts of treadwall climbing.

Introduction

Rock climbing is a dynamic, multi-faceted sport dominated by isometric contractions of the finger flexors (Giles et al., 2006; Grant et al., 1996, 2003; Sheel, 2004; Watts et al., 2004). There are many subdisciplines of rock climbing such alpinism, aid climbing and bouldering. One of the most popular forms, free climbing, involves using strictly the hands, feet and safety equipment to ascend a rock face (Roper, 1998).

Free climbing requires muscular strength and endurance in the finger flexors. During an ascent, the *flexor digitorum superficialis* (FDS) and surrounding forearm musculature produce tension while performing sustained, isometric contractions against rock holds (Macleod et al., 2007; Schweizer & Furrer, 2007). It has been observed that climbers' contract and relax the forearm musculature at a 13:1 ratio during an ascent (White & Olsen, 2010). Due to the repetitive nature of these contractions, muscular fatigue can become an issue.

Muscular fatigue has been defined as a decline in maximum force production or the inability to maintain a level of force production (Enoka et al., 1988). Fatigue during rock climbing has been associated with blood perfusion and reduced clearance rate of metabolic byproducts (Macleod et al., 2007). During exercise, ATP production creates metabolites such as hydrogen ions and carbon dioxide (Kenny et al., 2012). These metabolites are typically buffered or removed by circulating blood. Isometric contractions reduce blood perfusion to the working tissue, thereby reducing the removal rate (Kenny et al., 2012). As exercise continues, the musculature becomes acidotic, resulting in decreased cross bridge strength, contraction strength, and changes in muscular activity (Kenny et al., 2012; Cram et al., 2003). At all levels of experience, fatigue of the forearms affects climbing performance and is the primary cause of failure during a climbing ascent (Phillippe et al., 2012).

As climbing standards have progressed, advanced climbers began training the forearm musculature to resist fatigue (Goddard & Neumann, 1993, Hague & Hunter, 2006). It has been suggested that trained rock climbers have unique adaptations such as greater time to fatigue (TTF), finger force production (FP) and differences in muscle activity when compared to novices and untrained individuals. (Grant et al., 1996; Watts et al., 1996; Macleod et al., 2007, Vigoroux et al., 2014).

Many studies have analyzed the effects of rock climbing ability on FP, however few studies analyzed change in FP (ΔFP) during fatigued states (Grant et al., 1996, 2003; Mermier et al., 2000; Schweitzer & Furror, 2007; Phillippe et al. 2012; Vigoroux et al., 2014; Watts et al., 2004;). Of those studies, there is a large variability in hand strength testing apparatus and fatigue-inducing protocol. For example, sustained and intermittent contractions on a hangboard, mounted force plate, and handgrip dynamometer have been utilized in the literature for measuring ΔFP (Grant et al., 1996, 2003; Limonta et al., 2015; Watts et al., 1996, 2008).

Even fewer studies have paired FP and electromyopgrahy (EMG) to measure fatigue within rock climbers (Esposito et al., 2009; Limonta et al., 2015; Vigoroux & Quaine, 2006; Watts et al., 2003, 2008). Electromyography is a means of measuring motor unit action potentials within muscle tissue. Post-processing techniques such as root mean square (RMS) and median frequency (MF) can be utilized to estimate changes in motor unit recruitment. Previous research suggests advanced climbers have functional differences in fiber recruitment and a resistance to fatigue during fatiguing protocols.

While these studies shed light on differences between advanced and novice climbers, they do during insulated tasks. Only two previous studies have utilized climbing as a means of fatiguing subjects, however difficult, steep climbing was employed to induce fatigue and handgrip dynamometry was utilized to measure ΔFP (Watts et al., 1996, 2003). Later research by Watts et al. (2008) demonstrated handgrip dynamometry lacks specificity to common hand configurations in rock climbing. To the author's knowledge, no studies have analyzed differences between advanced and novice rock climbers in terms of FP and EMG during bouts of intermittent climbing on a treadwall system.

The purpose of the present study is to investigate the effect of rock climbing ability level on TTF, relative force production (REL FP), ΔFP, ΔMF and ΔRMS during bouts of intermittent treadwall climbing. We hypothesize advanced climbers will have a greater TTF, greater REL FP, lesser ΔFP, lesser ΔMF and lesser ΔRMS when compared to novice climbers.

Methods

Informed Consent

Prior approval of the study's protocol was obtained from the Montana State University Institutional Review Board (IRB), and all subjects provided Informed Consent prior to participating. The study's procedures, risks and benefits were explained in full. Subjects were made aware of the ability to withdraw from the study at any point. All data were coded and stored in a password-protected computer. All personal information was kept on a password-protected computer in the Movement Science Laboratory at Romney Gymnasium on the Montana State University campus.

Subjects

Fifteen rock climbers from the greater Bozeman area participated in the study. Subjects completed the subject data collection form (Appendix B) with pertinent variables related to ability level. Subjects were selected for ability group (advanced versus novice) based on self-reported ability level, years of rock climbing experience, and mean onsight grade. (Draper et al., 2016). Onsight grade refers to most difficult grade a climber could complete with no falls on the first attempt and no prior knowledge (Watts et al., 1996).

Experimental Design

This descriptive study uses a between-subject (advanced versus novice) and within-subject (dominant versus non-dominant hand) fixed measure with repeated measurements (pre- to post-exercise) to determine differences in rock climbers during bouts of intermittent treadwall climbing. Comparisons were made pre- and post-exercise treatment, as subjects served as their own control.

Subjects reported to the lab on one occasion. Each subject completed a pre-exercise bilateral maximum voluntary isometric contraction ($MVIC_{PRE}$) against a mounted force plate. Subjects climbed for five minute intervals and repeated the MVIC protocol following six climbing intervals or until failure. Force and EMG data were collected during each MVIC. Group and handedness comparisons were made at the 25 minute mark ($MVIC_{POST}$) to control for differences in climb time. The dependent variables measured during $MVIC_{PRE}$ and $MVIC_{POST}$ was REL FP. The pre-exercise MVIC also served as the baseline for ΔFP, ΔMF, ΔRMS. Change over time was calculated from $MVIC_{PRE}$ to $MVIC_{POST}$. Slope of FP during MVIC trials was calculated for $MVIC_{PRE}$, $MVIC_3$ and $MVIC_{POST}$.

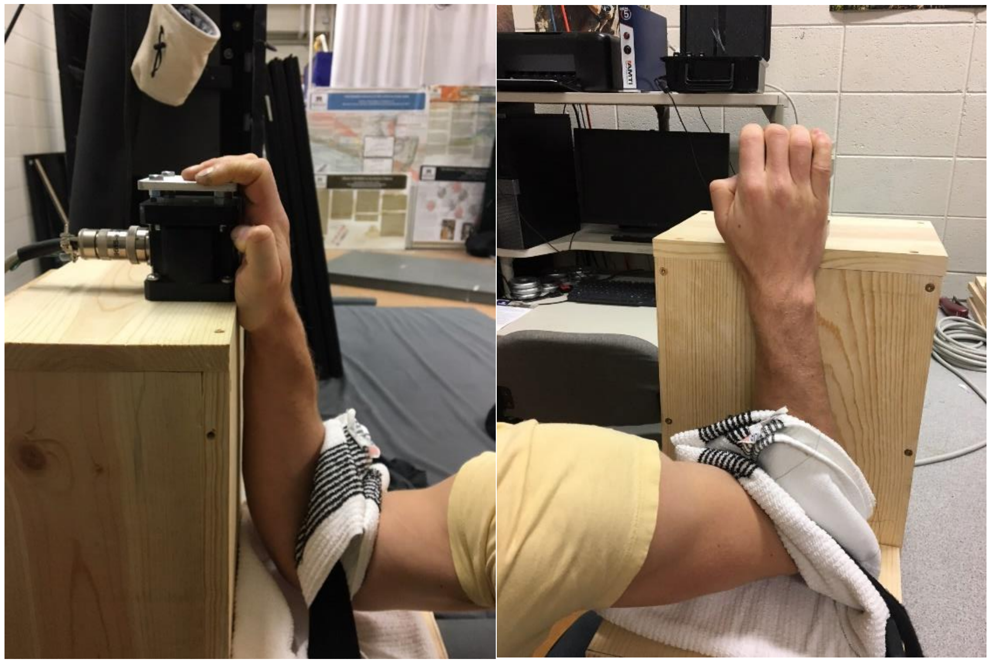
Experimental Procedure

Subject Selection To qualify for the advanced group, male subjects must consistently climb a minimum of 8.33/5.12a metric Union Internationale des Associations d'Alpinisme (UIAA)/Yosemite Decimal System (YDS) rating (Draper et al., 2016). Advanced female subjects must consistently climb a minimum of 7.33/5.11b metric UIAA/YDS. Both advanced sexes must have at least five years of climbing experience. Novice subjects, both male and female, must be able to climb up to 6.33/5.10a metric UIAA/YDS and have at least one year of climbing experience. All subjects must be primarily route climbers (>50% of reported time climbing). All subjects are to be free of any major illness or injury within the last six months. Participants must be able to climb for at least 15 minutes on slightly overhung 5.66/5.9 metric UIAA/YDS terrain.

Informed Consent and Procedure Overview Consenting subjects reported to the Movement Science Laboratory in Romney Gym on the Montana State University campus. Subjects completed the informed consent and physical activity readiness questionnaire (PAR-Q). The protocol of the experiment was fully explained. The protocol consisted of: a warm-up, habituation, and calibration period for the treadwall and mounted force plate, a period for placing and testing EMG electrodes, a pre-excise maximal fingertip contraction ($MVIC_{PRE}$), and finally the climbing protocol with subsequent bilateral MVICs after every five minutes of climbing.

Warm-Up and Habituation Subjects were given five minutes to warm-up and become habituated to the treadwall system (The Rock™, Ascent). Subjects then completed the mock hand-strength test. A means of measuring climbing-specific FP using a mounted force plate (AMTI© MC3A-1000, Watertown, MA) was adopted from Grant et al. (1996). The mounted force plate has been determined to be a reliable measure by Watts & Jensen (2003). This hand strength testing apparatus was designed to mimic typical body position and hand configuration seen during rock climbing. The mock test involved two, submaximal 20-second isometric contractions against the force plate with the dominant hand (DH) and non-dominant hand (NDH). This was performed to habituate the subject to the apparatus. The mock test also served as a means of standardizing arm angles and hand configuration for each participant. Arm position was standardized to 120º of horizontal abduction at the shoulder and 90º of elbow flexion (Grant et al., 1996). The elbow rest was adjusted to place subjects in 0º of wrist flexion and 90-100º of finger flexion at the proximal interphalangeal joint (Schweizer & Furrer, 2007). (Figure 1.) All joint angles were measured manually with a goniometer (Riddle et al., 1987). Subjects were instructed to utilize a half-crimp position during the test—that is, without the use of the thumb and creating force at the PIP joint. Subjects were also instructed to find a hand configuration that could be replicated for each trial.

Figure 1: Mounted force plate and arm configuration during MVIC test.



Electromyographic Electrode Placement EMG electrodes (Delsys Trigno™ Wireless EMG, Natick, MA) were placed over the belly of the *flexor digitorum superficialis* (FDS), *biceps brachii* (*biceps*) and *triceps brachii* (*triceps*). The FDS was chosen as it is the primary muscle activated during finger flexion at the proximal interphalangeal joint (Schweizer & Furrer, 2007). The *biceps* and *triceps* were chosen due to their importance in stabilizing the elbow joint. The FDS belly was located by asking subjects to flex the middle three digits at the PIP joint against an external force described by as Blackwell et al. (1999). The muscle bellies of the *biceps* and *triceps* were found as described by Cram et al. (2003). Electrodes were placed over the muscle belly with respect to the pennation angle of the muscle (Cram et al., 2003). Skin preparation techniques included removal of hair, abrasion of skin and cleansing with alcohol to reduce noise and ensure a consistent signal across subjects. A preliminary test was performed to ensure the electrode had been placed correctly. This involved asking the subjects to contract each muscle against an external force while recording live data. The electrodes were then fixed with sports tape and secured with athletic pre-wrap.

MVIC Test Protocol After subjects had warmed-up and been outfitted with EMG sensors, the pre-exercise maximum voluntary isometric contraction test ($MVIC_{PRE}$) was performed. This served as the baseline level for ΔFP, ΔμMF, and ΔRMS for post-exercise comparison. The MVIC test was performed as follows: one maximal 20 second fingertip contraction with both the DH and NDH. A countdown was given, at which point both data recording instruments were triggered simultaneously. Verbal encouragement in the form of "squeeze!" was given at the 10, 15 and 18 second mark.

Climbing Protocol The treadwall was set to a slight overhang, 7º off-vertical, to promote fatigue in the finger flexors (Balášet al., 2014, Watts & Drobish, 1998). The route was set with the assistance of USA Climbing-certified route setters at a 5.66/5.9 metric UIAA/YDS level. Plastic holds were placed so there was only one route the subjects may take. Subjects were informed to not skip holds. All holds were large, in-cut jug holds with the exception of two, smaller crimps. The two crimps served as the crux of the route and functioned to specifically fatigue the FDS. Subjects were allowed to drop one arm between holds, however subjects were not allowed to rest or "shake out" during the test, as that may have dislodged the EMG electrodes.

Following the $MVIC_{PRE}$ test, subjects began the climbing protocol on the treadwall. Subjects climbed for five minute intervals at a speed of seven meters/min.

Following the five minutes of climbing, subjects immediately performed another MVIC test beginning with the DH. No rest was given between DH and NDH except to move the subject's chair to the appropriate position. In total, MVIC tests were kept to a maximum of two minutes to ensure subjects were not able to recover. Once both hands were tested, subjects immediately climbed for another five minutes. This was repeated for a maximum of six sets (30 min. of climbing) or until failure. Immediately after failure or completion of the climbing protocol, a final MVIC ($MVIC_{POST}$) was recorded.

Data Analysis

Data collection consisted of one pre-exercise MVIC with the DH and NDH ($MVIC_{PRE}$) and up to six MVICs per side during the climbing protocol ($MVIC_1$, $MVIC_2$, …, $MVIC_{POST}$). Subjects were required to complete at least three bouts of climbing before failure. Inability to do so resulted in disqualification from the study. Between-group comparisons were made at the fifth MVIC ($MVIC_{POST}$) to account for differences in climb time.

Time to Fatigue Time to fatigue was measured using a stop watch on the treadwall. Time was stopped during MVIC tests and resumed during climbing intervals. Time to fatigue was recorded when the climber reached failure. Failure was defined as the point the subject fell from the treadwall. Time to fatigue data was analyzed in Microsoft Excel®.

Force Plate Data Force data was recorded in AMTI NetForce™ software and collected at 4096 Hz. It was converted via an AMTI© Gen 5 Advanced 6 Channel A/D amplifier. Force plate data was analyzed using MatLab™ software (Mathworks®, Natik, MA).

A Matlab™ code was written to read, filter, trim, calculate FP and slope of FP from $MVIC_{PRE}$ to $MVIC_{POST}$ (Appendix F). The raw data was read into MatLab™ and filtered using a low pass 2^{nd} order Butterworth filter with an 8 Hz cut-off. The cut-off was determined by running a residual analysis on the data to maintain 95% of the initial signal's power. The beginning and ending of each contraction was determined by sight. Data was trimmed to remove zeroes before and after the contraction. The remaining 20 second contraction had the first and last two seconds cropped to remove transient phenomena, yielding a usable data set 16 seconds in length.

Pre-exercise MVIC was used to determine subject's maximal force production (FP_{MAX}). FP_{MAX} was calculated by averaging the first five seconds of the filtered, cropped $MVIC_{PRE}$ trial (seconds two through seven). The remaining trials were averaged over the full 16 seconds. Average FP per trial was divided by FP_{MAX} to normalize ΔFP amongst all subjects over time.

Relative force production (N/kg) during $MVIC_{PRE}$ and $MVIC_{POST}$ was analyzed in Microsoft Excel®. Average values for each 16 second trial were imported into a spreadsheet and divided by the body weight of each participant in kilograms to derive the relative values.

Slope of FP over the course of each MVIC trial was calculated with a linear line of best fit to each data set. Slope of each trial was imported and analyzed in Microsoft

Excel®. Slopes for $MVIC_{PRE}$, $MVIC_3$, and $MVIC_{POST}$ were averaged by group and handedness.

EMG Data Electromyographic data was recorded in Delsys EMGWorks® Acquisition software and collected at 1926 Hz. It was converted from digital to analog via a 16-bit A/D board (National Instruments USB-6225, Austin, Texas, USA). Electromyographic data was analyzed in Delsys EMGWorks® Analysis and filtered using a zero-phase low pass 4^{th} order Butterworth filter with 300 Hz cut-off. Filter cut-off was determined by previous literature (Limonta et al., 2015; Vigouroux & Quaine, 2004).

The beginning and end of each contraction was time-matched with the corresponding force plate data. The data was trimmed to remove zeroes before and after the contraction. The first and last two seconds of each trial were cropped, resulting in a usable data set 16 seconds in length. All calculations run on trimmed EMG data utilized the standard RMS and MF calculations put forth by Delsys with no alternations. Delsys calculations have been independently verified (Hu, 2012; 2013; 2014). All data analysis was run on cropped data for RMS and MF in the FDS, *biceps*, and *triceps*.

Change in motor unit amplitude was reported as ΔRMS. Change in motor unit type was reported as ΔMF (De Luca, 1997). Root mean square was calculated on the filtered, cropped data. The time window utilized was 125 ms with a window overlap of 62.5 ms. Time values were based on practices found in previous literature (Clancy et al., 2005). The RMS value for each MVIC was determined by averaging the 16 seconds of data. Resultant values were exported and stored in Microsoft Excel®.

Median frequency was also calculated on the filtered, cropped data. A Fast-Fourier Transformation was performed, resolving the signal to a frequency-domain. Median frequency was then calculated as the frequency in which the signal's power was equally distributed. The average of the MF for each 16 second contraction was exported to a Microsoft Excel® spreadsheet.

Root mean square and MF were analyzed for each run and compiled in a single spreadsheet. Both RMS and MF were expressed as percent change from $MVIC_{PRE}$ to $MVIC_{POST}$ in order to normalize change over time for each participant.

Statistical Analysis

Unpaired T-Tests were used to analyze subject characteristics and TTF. A 2x2x2 (group by hand by time) mixed ANOVA was used to analyze REL FP during $MVIC_{PRE}$ and $MVIC_{POST}$. A 2x2x3 (group by hand by time) mixed ANOVA was used to analyze slope of FP during $MVIC_{PRE}$, $MVIC_{3}$, and $MVIC_{POST}$. A 2x2 (group by hand) mixed ANOVA was used to analyze ΔFP, ΔMF, and ΔRMS from $MVIC_{PRE}$ to $MVIC_{POST}$. If significant interactions were observed, a Bonferroni post-hoc test was performed to determine where the differences occurred. Significance level was set at $p \leq 0.05$. See Appendix D for statistical summary table. All statistics are reported as mean ± standard deviation (SD).

Results

Subject Characteristics

Age (*p=0.001*), years of climbing experience (*p=0.001*), mean project grade (*p=0.001*) and mean onsight grade (*p=0.002*) were significantly different between advanced and novice participants. Two novice subjects were excluded from data analysis due to premature failure, reducing the novice group from nine to seven. Excluded novice subjects climbed for six and eight minutes. Subject characteristics are summarized and reported in Table 1.

Subject	**n**	**Age**	**Weight**	**Height**	**Years Experience**	**Mean Onsight Grade**	**Mean Project Grade**
Nov	7	21 ± 2.3*	67.6 ± 3.8	67.6 ± 3.8	3.0 ± 2.6*	6.0 ± 1.0*	6.3 ± 0.4*
Adv	8	29.3 ± 4.7	69.1 ± 6.9	69.1 ± 6.9	11.1 ± 5.2	8.6 ± 0.4	10.3 ± 0.4

Table 1: *Subject Selection Summary Table*. Self-reported mean age, weight (kg), height (cm), and years of climbing experience. Onsight grade refers to most difficult grade subject could complete with no falls on the first attempt and no prior knowledge. Project grade refers to most difficult grade subject could complete with an appropriate amount of time and prior knowledge. Climbing grades reported in metric UIAA rating scale.
* = significant differences between groups at $p<0.05$. Reported as mean ± SD.

Time to Fatigue

Time to fatigue was longer for advanced climbers (30 ± 0 min.) compared to the novice climbers (25.7 ± 3.6 min., *p=0.001*). All advanced subjects completed the climbing protocol. Only one novice subject completed the 30 minute protocol.

Relative Force Production

There was no significant group by hand by time interaction observed for REL FP (*p=0.354*). No significant group by time (*p=0.304*) or hand by time (*p=0.511*) interactions were observed. There was no main time (*p=0.391*) effect observed; however, a significant group by hand interaction was observed for REL FP (*p=0.008*). A post-hoc tests revealed the advanced groups' DH (5.6 ± 1.2 N/kg) produced more force than the advanced NDH (5.2 ± 1.3 N/kg, *p=0.004*). Moreover, the advanced group produced more force (5.4 ± 1.3 N/kg) when compared to the novice group (3.2 ± 0.9 N/kg, *p=0.001*). (Table 2, Figure 2).

Change in Force Production

There was no group by hand interaction observed for ΔFP (*p=0.505*). There was no significant main hand effect observed (p=0.415). However, a significant main group effect was observed for ΔFP (*p*=0.001). The advanced group experienced no change in ΔFP, while the novice group ΔFP decreased (-27.8 ± 16.7%) from $MVIC_{PRE}$ to $MVIC_{POST}$. (Table 2, Figure 4).

		REL FP	**ΔFP**
Adv	DH	5.6 ± 1.2**	+1.5 ± 12.3
	NDH	5.2 ± 1.3**	+2.0 ± 16.6
Nov	DH	3.2 ± 0.8	-30.8 ± 16.0*
	NDH	3.2 ± 1.0	-24.9 ± 18.6*

Table 2: *Finger force production summary*. Relative force reported in N/kg body weight. ΔFP reported from $MVIC_{PRE}$ to $MVIC_{POST}$. ** = significant groups by hand interaction, * = significant group differences at $p<0.05$. Reported as mean ± SD.

Slope of Force Production

There was no group by hand by time interaction observed for slope of force production ($p=0.993$). There was no group by time ($p=0.322$), group by hand ($p=0.947$) or hand by time ($p=0.054$) interaction observed. There were no main group ($p=0.088$), time ($p=0.285$) or handedness ($p=0.249$) effects observed for slope of force production. This is due to inconsistency in force production during the 16-second MVIC.

Change in Median Frequency & Root Mean Square

There was no group by hand interaction observed for FDS ΔMF ($p=0.780$) or ΔRMS ($p=0.763$). No significant main hand effect was observed for FDS ΔMF ($p=0.555$) or ΔRMS ($p=0.214$). However, a significant main group effect was observed for FDS ΔMF ($p=0.002$), but not ΔRMS ($p=0.135$). (Table 3). The advanced group experienced no change in ΔMF, but the novice group's ΔMF decreased (17.6 ± 10.9%). (Figure 5). Neither advanced nor novice participants experienced a change in RMS. (Figure 6).

		ΔMF	ΔRMS
Adv	**DH**	+4.8 ± 25.9	+2.8 ± 17.5
	NDH	+7.7 ± 18.8	+30.7 ± 39.1
Nov	**DH**	-22.7 ± 6.5*	-18.3 ± 29.7
	NDH	-12.6 ± 15.5*	-12.9 ± 17.5

Table 3: *Percent change in MF and RMS in the FDS muscle*. MVC_{PRE} to MVC_{POST}. * = significant differences between groups at $p<0.05$. Reported as mean ± SD.

There were no significant group by hand interactions observed for *biceps* ΔMF ($p=0.157$), ΔRMS ($p=0.367$) or *triceps* ΔMF ($p=0.643$), ΔRMS ($p=0.470$). There were no significant main group effects observed for *biceps* ΔMF (*p=0.150*) or ΔRMS (*p=0.748)* nor in *triceps* ΔMF (*p=0.594*) or ΔRMS (*p=0.753*). There were no main hand effects observed for *biceps* ΔMF (*p=0.966*), ΔRMS (*p=0.129)* or *triceps* ΔMF (*p=0.130*), ΔRMS (*p=0.354)* (Table 4).

		ΔRMS		ΔMF	
		Biceps	***Triceps***	***Biceps***	***Triceps***
Adv	**DH**	+2.7 ± 38.1	-6.7 ± 17.1	+12.0 ± 33.8	+16.8 ± 19.0
	NDH	+17.7 ± 93.7	+7.2 ± 15.9	+17.0 ± 35.3	+1.77 ± 22.36
Nov	**DH**	-20.7 ± 27.7	+85.0 ± 89.0	-15.5 ± 15.6	+13.7 ± 11.2
	NDH	-7.3 ± 48.8	-13.8 ± 63.1	-14.4 ± 25.2	-7.7 ± 13.1

Table 4: *Percent change in MF and RMS in the BB and TB muscles*. MVC_{PRE} to $MVC_{POST.}$ Reported as mean ± SD.

*Figure 2: Relative FP of advanced and novice participants during $MVIC_{PRE}$. * p≤0.05*. Reported as mean ± SD.

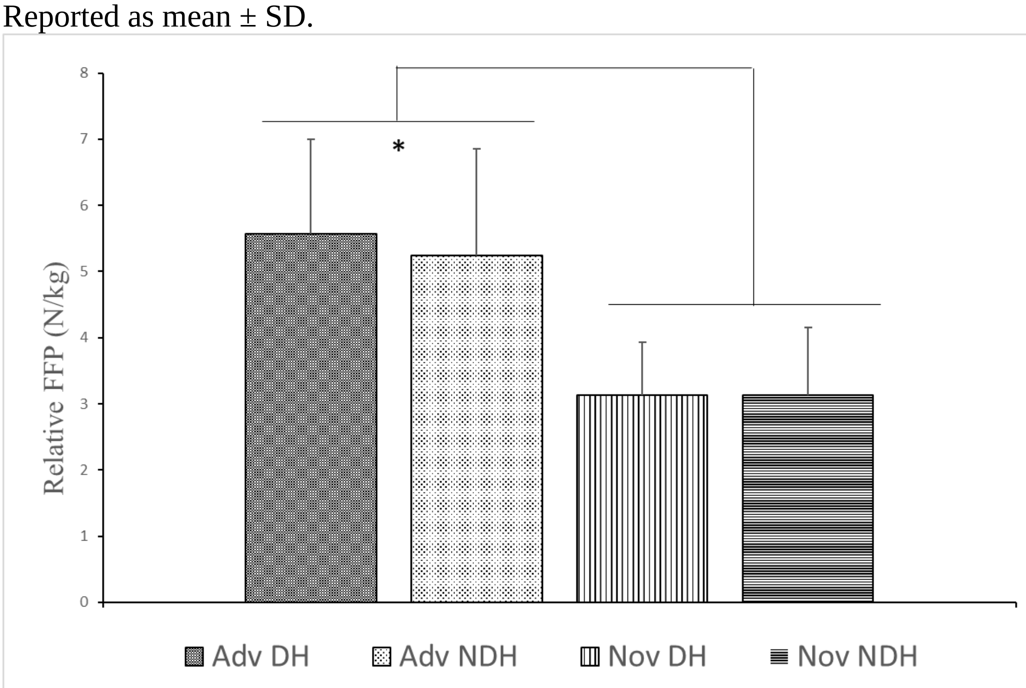


Figure 3: Relative FP of advanced and novice participants during MVICPOST. *$p \leq 0.05$. Reported as mean ± SD.

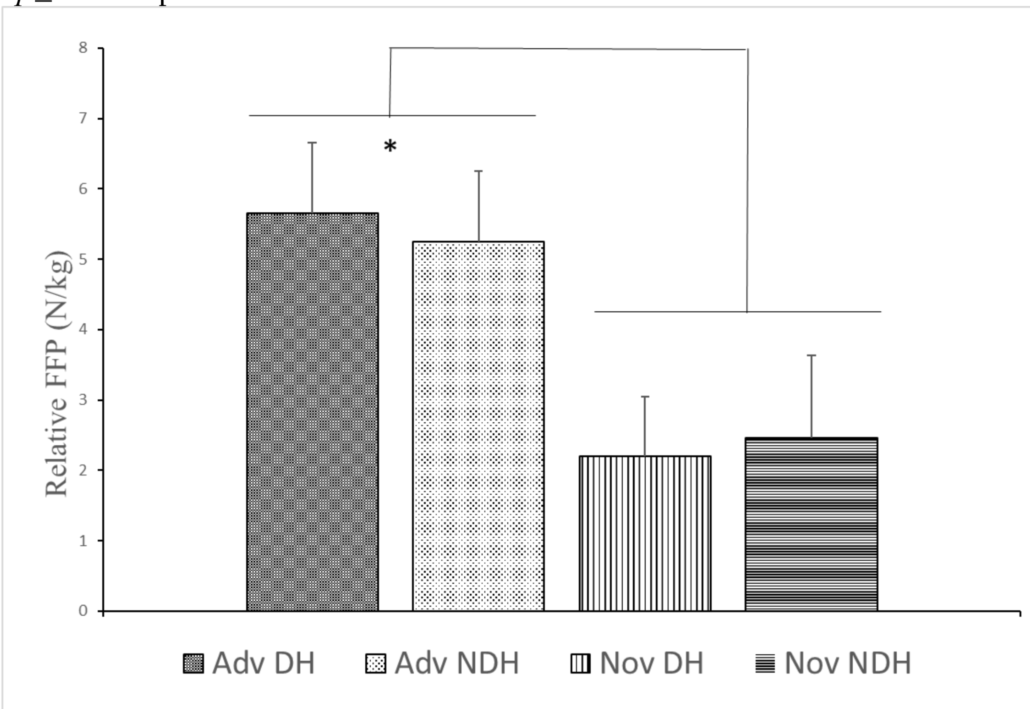


Figure 4: *FP Percent Change.* Advanced vs. Novice climbers ΔFP for $MVIC_{PRE}$ to $MVIC_{POST}$. * $p \leq 0.05$. Reported as mean ± SD.

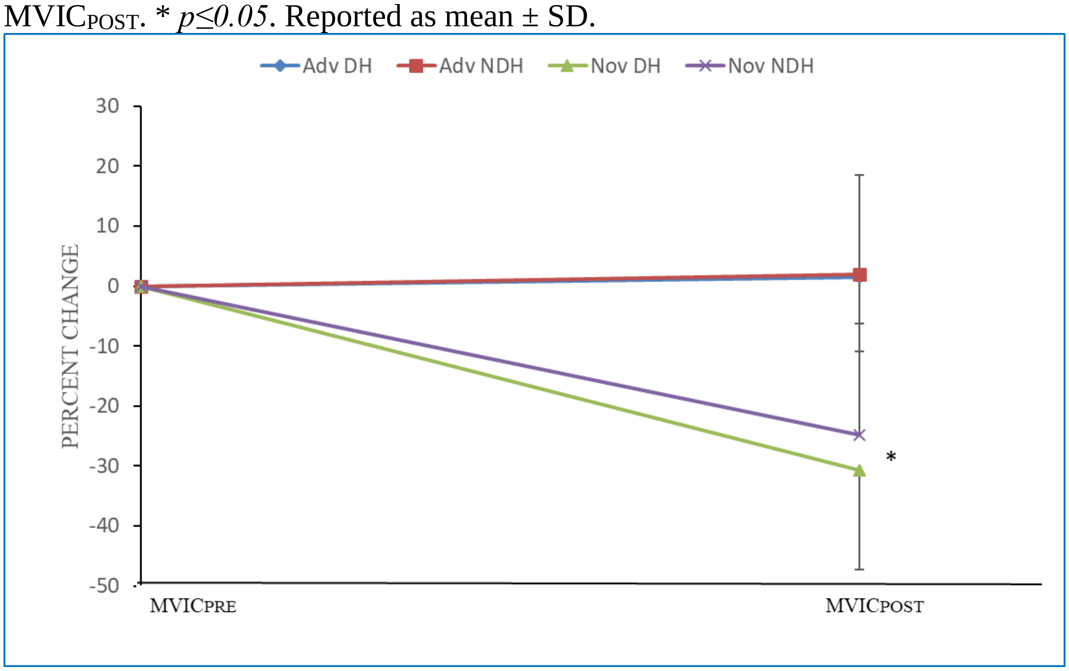


Figure 5: FDS MF Percent Change. Advanced vs. Novice climbers ΔMF for $MVIC_{PRE}$ to $MVIC_{POST}$. * *$p \leq 0.05$*. Reported as mean ± SD.

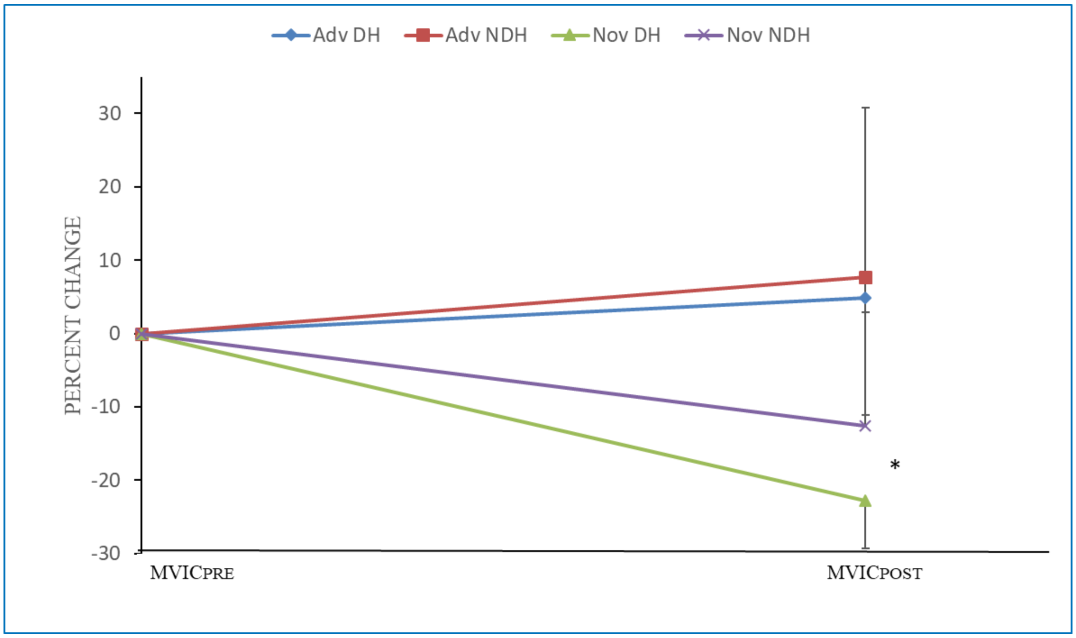
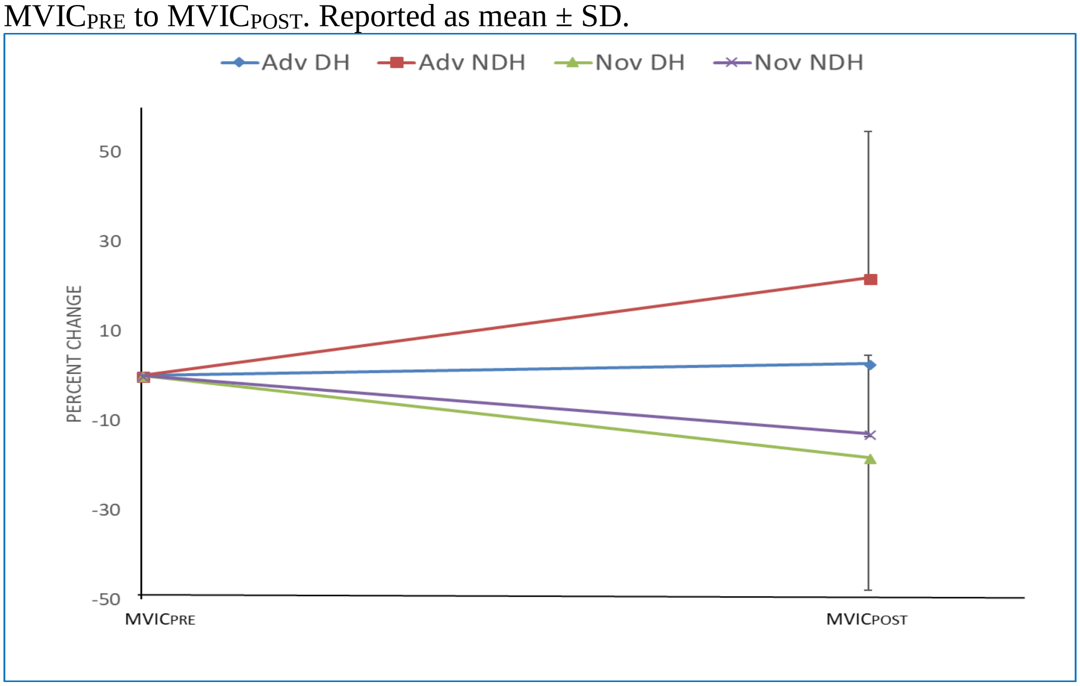


Figure 6: FDS RMS Percent Change. Advanced vs. Novice climbers ΔRMS for $MVIC_{PRE}$ to $MVIC_{POST}$. Reported as mean ± SD.



Discussion

The purpose of the present study was to determine if rock climbing ability affects climber's muscular fatigue of the *flexor digitorum superficialis* during treadwall climbing. Results of this study demonstrate advanced climbers have resistance to fatigue when compared to novice climbers. Advanced and novice subjects climbed on a treadwall for five minute intervals, followed by a bilateral 20 second MVIC against a mounted force plate. Force production and EMG data were measured during the MVIC tests. Fatigue was measured by TTE, REL FP, ΔFP, ΔMF and ΔRMS.

Time to Fatigue

The hypothesis that advanced climbers have a greater time to fatigue during treadwall climbing was supported by the findings. Only one novice climber completed the full 30-minute protocol, however the subject's force production decreased 9.8% and 16.7% in the DH and NDH, respectively. Previous studies have reported similar results. Grant et al. (1996) demonstrated climbers have greater localized endurance of the arms during a bent arm hang and Vigoroux & Quaine (2006) indicated climbers have greater TTF during fatiguing contractions against a force plate similar to the one utilized in the present study. Only one previous study reported no difference between trained and untrained subjects in TTF, however the hand strength testing apparatus lacked specificity to rock climbing (Ferguson & Brown, 1997; reported by MacLeod, 2007).

Relative Force Production

Advanced climbers had greater REL FP during $MVIC_{PRE}$ and $MVIC_{POST}$ when compared to novice climbers. Previous literature described similar findings. Watts et al. (1993) reported advanced/elite climbers are in the 50^{th} to 75^{th} percentile of absolute handgrip strength, but in the 80^{th} to 90^{th} percentile of handgrip strength relative to body weight when compared to the North American age-matched norms. Moreover, climbers are known to be smaller stature and have less body fat compared to sedentary subjects (Watts et al., 1996; Mermier et al., 2000). MacLeod et al. (2007), Phillippe et al. (2012), and Fryer et al. (2014a, 2014b) reported comparable results using similar isometric hand strength testing apparatus. These studies also reported an increasing trend in MVIC with rock climbing ability, illustrating the importance of strength-to-weight ratio in high-performance rock climbing.

Change in Force Production

The novice group experienced a greater ΔFP from $MVIC_{PRE}$ to $MVIC_{POST}$ when compared to the advanced group. Macleod et al. (2007), Vigoroux et al. (2014) and Limonta et al. (2015) reported less decline in FP with a longer TTF in trained subjects when compared to novice/untrained individuals. In the present study, the novice group's FP tapered from $MVIC_{PRE}$ to $MVIC_{POST}$, decreasing by 24-30% (and as much as 61%) at the point of failure. The advanced group, however, experienced no statistical change in ΔFP. One advanced climber increased FP by 23% at the 30 minute mark when compared to MVICPRE. These findings build upon previous research that suggests advanced climbers have a resistance to forearm fatigue during both intermittent contraction tests of relative intensity and during sustained climbing at an absolute level (5.9 YDS).

EMG Data

Electromyographic data collected from the FDS supports the hypothesis for ΔMF, but not ΔRMS. There was no statistical change in advanced ΔMF from $MVIC_{PRE}$ to $MVIC_{POST}$, while the novice group's ΔMF decreased by 22% and 12% in the DH and NDH, respectively. Median frequency findings agree with Vigoroux & Quaine (2006) and Esposito et al. (2008), who found elite-level climbers decline less in MF during fatiguing contractions at 20-80% MVIC when compared to non-trained counterparts. Previous research also demonstrates a correlation between MF and contraction intensity, relating to the recruitment of larger motor units with higher conduction velocity (Stulen & DeLuca, 1981, reported by Esposito et al., 2008). While not conclusive, the decline in force production and MF could be explained by the exhaustion of Type IIa/x fibers in the novice group's forearm musculature.

No statistical difference was found in FDS ΔRMS however trends were observed similar to ΔFP and ΔMF. Watts et al. (2003) found similar results, indicating that once the point of failure is reached in rock climbers, there is little change in RMS during maximal contractions. This could be due to a reliance on fatigue-resistant Type I motor units to produce force when the Type IIa/x have been exhausted.

Bicep brachii and *triceps brachii* results did not yield any statistically significant findings. These muscles were measured to determine if there was shifting of force production during fatigued states, similar to fatigue responses seen in other trained athletes (Enoka et al., 1992). Results of this study indicate there was no change in activation over time. Due to possible movement of electrodes and interference of sweat, only seven advanced and four novices subjects' *biceps* and *triceps brachii* activity could be analyzed. More research should be devoted to general muscle activity and muscular compensation during fatigued states in climbers.

Conclusion

In conclusion, advanced rock climbers do have a resistance to fatigue during bouts of treadwall climbing. The present study measured FP as well as muscle activity in the *flexor digitorum superficialis*, *biceps brachii,* and *triceps brachii* during an intermittent climbing protocol. The advanced group demonstrated increased TTF, greater FP relative to body weight, less change in FP, and a lesser ΔMF after 25 minutes of climbing. Concurrently, the novice group quickly declined in finger force production, which was mirrored in the EMG results. While there are many possible explanations for this phenomenon, it is very possible that years of training adaptations resulted in less fatigue over time or greater recovery during relaxation periods.

Future studies may utilize a similar protocol to compare groups closer together in ability or compare different climbing subdisciplines (boulderer vs. sport climber vs. alpinist). The protocol presented could be utilized to analyze rock climbing-specific aerobic or anaerobic capacity, supplementation or during training interventions. Route difficulty could be modulated relative to each subject's ability level or different holds and movements utilized.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPLICATION & APPROVAL

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MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

960 Technology Blvd. Room 127
c/o Microbiology & Immunology
Montana State University
Bozeman, MT 59718
Telephone: 406-994-6783
FAX: 406-994-4303
E-mail: cherylj@montana.edu

Chair: Mark Quinn
406-994-4707
mquinn@montana.edu
Administrator:
Cheryl Johnson
406-994-4706
cherylj@montana.edu

MEMORANDUM

TO: Philip Ferrara, Ashleigh Phillips, Cory Synder, Samantha Bessert, John Seifert

FROM: Mark Quinn *Mark Quinn cj*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: April 5, 2017

SUBJECT: *"Changes in Muscle Activity of the Forearms during Fatigued States in Advanced Rock Climbers"* [PF040517]

The above proposal was reviewed by expedited review by the Institutional Review Board. This proposal is now approved for a period of one-year.

Please keep track of the number of subjects who participate in the study and of any unexpected or adverse consequences of the research. If there are any adverse consequences, please report them to the committee as soon as possible. If there are serious adverse consequences, please suspend the research until the situation has been reviewed by the Institutional Review Board.

Any changes in the human subjects' aspects of the research should be approved by the committee before they are implemented.

It is the investigator's responsibility to inform subjects about the risks and benefits of the research. Although the subject's signing of the consent form, documents this process, you, as the investigator should be sure that the subject understands it. Please remember that subjects should receive a copy of the consent form and that you should keep a signed copy for your records.

In one year, you will be sent a questionnaire asking for information about the progress of the research. The information that you provide will be used to determine whether the committee will give continuing approval for another year. If the research is still in progress in 5 years, a complete new application will be required.

MONTANA STATE UNIVERSITY

Institutional Review Board Application for Review

(revised 09/23/13)

****

THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA

Application Number: Approval Date:

Disapproved: IRB Chair's Signature:

****

Date: **March 10, 2017**

I. Investigators and Associates (list all investigators involved; application will be filed under name of first

person listed)

NAME: **Philip Ferrara** TITLE: **Graduate student**

DEPT: **HHD** PHONE #: 770-883-9177

COMPLETE ADDRESS: 1133 N. 14th Ave. Apt 107 Bozeman, MT 59715

E-MAIL ADDRESS: **Philip.ferrara@montana.msu.edu**

DATE TRAINING COMPLETED: **May 2016**

NAME: **Ashleigh Phillips** TITLE: **Undergraduate student**

DEPT: **HHD** PHONE #:518-338-6776

COMPLETE ADDRESS: 4239 W. Babcock St. #8 Bozeman, MT 57915

E-MAIL ADDRESS: Irishdancenator@gmail.com

DATE TRAINING COMPLETED: 2015

NAME: **Cory Synder** TITLE: **Graduate student**

DEPT: **HHD** PHONE #: 603-667-6428

COMPLETE ADDRESS: 3157 Summer View Lane Bozeman, MT 59715

E-MAIL ADDRESS: cosnyd@me.com

DATE TRAINING COMPLETED: 2016

NAME: **Samantha Bessert** TITLE: **Graduate student**

DEPT: **HHD** PHONE #:360-852-0312

COMPLETE ADDRESS: 4665 Bembrick St. Apartment 2A Bozeman, MT 59718

E-MAIL ADDRESS: Samantha.Bessert@gmail.com

DATE TRAINING COMPLETED: 2017

NAME: **Dr. John Seifert** TITLE: **Advisor**

DEPT: **HHD** PHONE #:406-994-7154

COMPLETE ADDRESS: PO Box 173360 Montana State University Bozeman, MT 59715

E-MAIL ADDRESS: John.Seifert@Montana.edu

DATE TRAINING COMPLETED: 2015

SIGNATURE (PI or ADVISOR): ________________________________

Do you as PI, any family member or any of the involved researchers or their family members have consulting agreements, management responsibilities or substantial equity (greater than $10,000 in value or greater than 5% total equity) in the sponsor, subcontractor or in the technology, or serve on the Board of the Sponsor? _____ YES **__X__** NO

If you answered Yes, you will need to contact Pamela Merrell, Assistant Legal Counsel-JD at 406-994-3480.

II. Title of Proposal: *[please try to keep title on front page]*

Changes in Muscle Activity of the Forearms in Climbers during Treadwall Climbing

III. Beginning Date for Use of Human Subjects:

May 2017

IV. Type of Grant and/or Project (if applicable)

Research Grant:

Contract:

Training Grant:

Classroom Experiments/Projects:

Thesis Project: X

Other (Specify):

V. Name of Funding Agency to which Proposal is Being Submitted (if applicable):

VI. Signatures

Submitted by Investigator

Typed Name: Philip F. Ferrara

Signature:

Date:

Faculty sponsor (for student)

Typed Name: John Seifert

Signature:

Date:

VII. Summary of Activity. Provide answers to each section and add space as needed. Do not refer to an accompanying Grant or contract proposal.

A. RATIONALE AND PURPOSE OF RESEARCH (What question is being asked?)

Rock climbing is a sport that has gained popularity over the last 30 years. It is a complex, multi-faceted activity that require a broad range of skills including muscular strength and endurance, coordination and mental fortitude.

Research exists on the physiology of rock climbers, particularly of the forearm musculature and its capacity to perform intense bouts of work. However, little has been done to investigate how forearm musculature contractions change with fatigue. Rock climbing has been characterized as "continuous isometric contractions of the forearms for upward propulsion." Isometric contractions occur when the muscle contracts against a fixed object such as a climbing hold; muscle tension increases however joint angle and muscle fiber length remains static. Due to the nature of isometric contractions, localized muscular fatigue of the forearms is the primary cause for failure during a climbing route. Understanding how this failure occurs and identifying early indicators is essential to rock climbing performance.

The purpose of this experiment is to investigate muscle activation differences in the forearms of novice and advanced rock climbers during non-fatigued and fatigued states. Of interest is how muscle fiber utilization and recruitment changes between the two conditions (fatigued and non-fatigued) using electromyography (EMG). Also of interest is how fatigue response may differ between the two groups (novice and advanced). Answering this question will provide information on how forearm muscles fatigue during actual bouts of rock climbing. This can be practically applied to improve training protocols, safety during training, and provide markers for when a climber may be fatigued. Moreover, this information could be used in future studies comparing supplementation during pre-fatigued and fatigued conditions.

B. RESEARCH PROCEDURES INVOLVED. Provide a short description of sequence and methods of procedures that will be performed with human subjects. Include details of painful or uncomfortable procedures, frequency of procedures, time involved, names of psychological tests, questionnaires, restrictions on usual life patterns, and follow up procedures.

***Pre-testing Protocol*. Subjects will visit the Movement Science Laboratory on one occasion. Subject will be required to complete the pre-requisite paperwork of informed consent, physical activity readiness questionnaire and health history**

questionnaire. As well, subjects will be given time to become habituated on the treadwall system.

***Treatment Protocol*. After the subject has warmed up and been outfitted with the diagnostic tools, the maximum voluntary contraction test (MVIC) will be performed. This test will provide a baseline reading of strength that will be used as comparison later to determine subject fatigue. During this test, EMG data will be recorded from the FDS. This will also serve as the baseline pre-fatigued readings that future MVICs will be compared against to determine the magnitude of fatigue. A means of measuring MVIC using a mounted force plate has been adopted from Grant et al. (1996, 2003). This apparatus is designed to mimic typical body position and ergonomics during rock climbing. The force plate (AMTI© MC3A-1000, Watertown, MA; sampled at 4096 Hz) will be mounted on a table top and the subject will sit with their dominant arm in 60º of horizontal abduction with respect to the shoulder girdle (Clancy et al., 2004; Grant et al., 1996). The subject will rest their elbow on an adjustable surface, which will be moved up or down to maintain a 90 degree angle at the elbow joint. An orthopedic brace will be placed over the subject's hand and forearm to ensure that flexion occurs only at the proximal interphalangeal joint (PIP). It is essential that the subject maintain a "crimp" position of the hand and flexion only occurs at the PIP joint (Schweizer & Furrer, 2007). This will ensure the FDS is the primary flexor involved with the contraction. Force data will be converted via an AMTI© Gen 5 Advanced 6 Channel A/D amplifier.**

The initial MVIC test will consist of four 5-second maximal isometric fingertip contractions against the plate with one minute of rest between each trial. Verbal encouragement will be given to ensure subject's scores are optimized. The highest of the four MVIC scores will be considered the true, pre-fatigued maximum.

Immediately following the MVIC test, subjects will begin to climb on the treadwall (The Rock™, Ascent). The treadwall will be set to vertical (90º) and plastic holds have been placed so there is only one route the subjects may take. Subjects may not rest or "shake out" during the test, as this may dislodge the EMG electrode placed on their forearm.

Participants will climb for 10 minutes. Following the 10 minutes of climbing, subjects will immediately perform another MVIC test. One minute of rest will be given between each maximum fingertip contraction, four trials will be taken again. Again, EMG data will be recorded during the MVIC tests. The highest value of the four trials will be compared against the initial MVIC and used to quantify fatigue. If the subject's highest MVIC is below 40% of their previous maximum, the subject will be considered "fatigued." If the subject is not below 40%, instruction will be given to climb for an additional 5 minutes or until volitional fatigue. At this point the MVIC test will be repeated.

This protocol will ensure that there is a difference between pre-fatigued and fatigued conditions, as well it gives researchers a quantifiable means of measuring fatigue.

Rating of perceived exertion will be recorded at the end of each interval during exercise using the Borg 6-20 scale.

***Instrumentation*. Electromyography will be recorded with the Delsys® EMG Trigno System. The treadwall being used is The Rock™ by Ascent. The force plate is a MC3A-1000 unit manufactured by AMTI®. Casting to ensure proper MVIC testing position has been provided by Bridger Orthopedics.**

***Statistical Analyses*. Data will be analyzed with StatPac and SPSS statistical software using a 1-way ANOVA with repeated measures. Alpha level of significance is set at $p \leq 0.05$.**

C. DECEPTION - If any deception (withholding of complete information) is required for the validity of this activity, explain why this is necessary and attach debriefing statement.

N/A

D. SUBJECTS

1. Approximate number and ages

   How Many Subjects: **Up to 12**

   Age Range of Subjects: **18-40y**

   How Many Normal/Control: **Up to 12 (crossover study)**

   Age Range of Normal/Control: **18-40 y**

2. Criteria for selection:

Healthy individuals with no major injuries in the last year and can climb for an extended period of time on vertical terrain. Novice climber should be able to climb up to 5.10a YDS and established in skill. Advanced climbers should have at least 5 years of experience and be able to climb at least 5.12a on the Yosemite decimal system. 5.12a classification denotes an advanced level climbing ability. Subjects will complete a questionnaire regarding ability level in order to obtain a homogenous test group.

3. Criteria for exclusion:

Those subjects who have asthma, breathing disorders, or are unable to complete the exercise protocol due to fitness level.

4. Source of Subjects (including patients):

MSU student population, Bozeman area climbers, Spire Climbing Center climbers

5. Who will approach subjects and how? Explain steps taken to avoid coercion.

Philip Ferrara or other investigators will approach subjects. Subjects will be informed that they are free to withdraw from the study at any time.

6. Will subjects receive payments, service without charge, or extra course credit?
   Yes or **No**
   (If yes, what amount and how? Are there other ways to receive similar benefits?)

7. Location(s) where procedures will be carried out.

MSU Movement Science Laboratory in Romney Gym

E. RISKS AND BENEFITS (ADVERSE EFFECTS)

1. Describe nature and amount of risk and/or adverse effects (including side effects), substantial stress, discomfort, or invasion of privacy involved.

There are risks to participating in this study. These include: fatigued or sore muscles and possible injury from falling from the treadwall. Thick foam matting will be placed below the treadwall to ensure safety in the event of an unexpected fall. Perceived exertion will be monitored throughout the testing. Subjects will be required to complete a health history form prior to participating which includes personal health information. This form will help screen potential health problems before the exercise. Subjects will be screened prior to the study for breathing disorders, precautions will be taken for their safety. There is no compensation available from MSU for injury

2. Will this study preclude standard procedures (e.g., medical or psychological care, school attendance, etc.)? If yes, explain.

None

3. Describe the expected benefits for individual subjects and/or society.

Results of this study will shed light on the difference between the motor unit recruitment and force development in pre-fatigued and fatigued states. Moreover, it aims to show how novice and advanced climbers fatigue differently due to years of experience or training. Recognizing fatigue in rock climbers could yield

improvements in training protocols, reduce injury rates and provide a basis for future studies comparing fatigued states.

F. ADVERSE EFFECTS

1. How will possible adverse effects be handled?

   By investigator(s):

   Referred by investigator(s) to appropriate care: **X**

   Other (explain):

2. Are facilities/equipment adequate to handle possible adverse effects? **Yes** or No

   (If no, explain.)

3. Describe arrangements for financial responsibility for any possible adverse effects.

   MSU compensation (explain):

   Sponsoring agency insurance:

   Subject is responsible: **X**

   Other (explain):

G. CONFIDENTIALITY OF RESEARCH DATA

1. Will data be coded? **Yes** or No

2. Will master code be kept separate from data? **Yes** or No

3. Will any other agency have access to identifiable data? Yes or **No**

   (If yes, explain.)

4. How will documents, data be stored and protected?

   Locked file: **X**

   Computer with restricted password: **X**

   Other (explain):

VIII. Checklist to be completed by Investigator(s)

A. Will any group, agency, or organization be involved? Yes or **No**

(If yes, please confirm that appropriate permissions have been obtained.)

B. Will materials with potential radiation risk be used (e.g. x-rays, radioisotopes)? Yes or **No**

1. Status of annual review by MSU Radiation Sources Committee (RSC). Pending or Approved

   (If approved, attach one copy of approval notice.)

2. Title of application submitted to MSU RSC (if different).

C. Will human blood be utilized in your proposal? Yes or **No**

(If yes, please answer the following)

1. Will blood be drawn? Yes or **No**
   (If yes, who will draw the blood and how is the individual qualified to draw blood?

   What procedure will be utilized?)

2. Will the blood be tested for HIV? Yes or **No**

2. What disposition will be made of unused blood?
4. Has the MSU Occupational Health Officer been contacted? Yes or **No**

D. Will non-investigational drugs or other substances be used for purposes of the research? Yes or **No**

Name:

Dose:

Source:

How Administered:

Side effects:

E. Will any investigational new drug or other investigational substance be used? Yes or **No**

[*If yes, provide information requested below and one copy of: 1) available toxicity data; 2) reports of animal studies; 3) description of studies done in humans; 4) concise review of the literature prepared by the investigator(s); and 5) the drug protocol.]*

Name:

Dose:

Source:

How Administered:

IND Number:

Phase of Testing:

F. Will an investigational device be used? Yes or **No**

(If yes, provide name, source description of purpose, how used, and status with the U.S. Food and Drug Administration FDA). Include a statement as to whether or not device poses a significant risk. Attach any relevant material.)

G. Will academic records be used? Yes or **No**

H. Will this research involve the use of:

Medical, psychiatric and/or psychological records Yes or **No**

Health insurance records Yes or **No**

Any other records containing information regarding personal health and illness Yes or **No**

If you answered "Yes" to any of the items under "H.", you must complete the **HIPAA worksheet**.

I. Will audio-visual or tape recordings or photographs be made? **Yes** or No

J. Will written consent form(s) be used? (**Yes** or No. If no, explain.) (Please use accepted format from our website. Be sure to indicate that participation is voluntary. Provide a stand-alone copy; do not include the form here.)

APPENDIX B

SUBJECT DATA COLLECTION SHEET

DATA COLLECTION SHEET

Name: ____ Gender: M F

Age: _________________ Height: _____'______" __________cm

Email address: ____

Phone: ____

EXPIRIENCE

Main Climbing Discipline (circle): Bouldering Sport Climbing Traditional Climbing Ice Climbing

Climbing Skill Level (circle): Beginner Intermediate Advanced Expert

Total Years Climbing Experience: _______________

Average Onsite Grade: ________________ Average Project Grade: ______________

Mean Training Time (in hours per week): _________________

Percentage of climbing days spent indoors/outdoors in past 12 months:

Indoor: _________________ Outdoor: ___________________

Are you now or have you ever been a competitive athlete (circle)? N Y

If so, what sport? _________________________________

How many years of experience?

____

Are you now or have you ever been a competitive climber (circle)? N Y

For test proctors:

Testing ID Number: __________________

PAR-Q complete and signed: Yes No

Informed Consent completed and signed: Yes No

APPENDIX C

SUBJECT INFORMED CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Title: Changes in Muscle Activity of the Forearms in Rock Climbers During Treadwall Climbing

You are being asked to participate in a research study on rock climbing and muscle fatigue. You will be asked to perform a number of maximum hand contractions as well as climb on the treadwall for up to 30 minutes.

The purpose of this experiment is to investigate muscle activation differences and force production in the forearms of novice and advanced rock climbers during non-fatigued and fatigued states. Answering these questions will provide information on how forearm muscles fatigue and force production declines over time.

Investigator: Philip Ferrara, Movement Research Lab

Procedures.

Pre-testing Protocol. You will visit the Movement Science Laboratory on one occasion. First, you will be required to complete the pre-requisite paperwork of informed consent, physical activity readiness questionnaire, and health history questionnaire. As well, you will be given 5 minutes to become habituated on the treadwall system.

Treatment Protocol. Once you have warmed up, you will be fitted with electromyographic (EMG) electrodes. These electrodes will be placed on the forearms, biceps, triceps and latissimus dorsi to record muscle activity in real time. A small 2-by-2 inch squares may need to be cleaned and shaved to obtain accurate readings.

You will then perform a maximum voluntary contraction (MVIC) test. A cast will be placed on your hand to ensure flexion occurs only at the finger joints. The MVIC test will consist of two 20-second maximal isometric fingertip contractions against a force plate. Verbal encouragement will be given to ensure your scores are optimized.

Immediately following the MVIC test, you will climb on the treadwall for 5-minute intervals with a maximum of 6 intervals or until failure. The treadwall will be set to slightly overhanging (-7º) and plastic holds have been placed so there is only one route you may take. The trial will begin when you begin climbing and will end after the 5 minutes interval. You may not rest or "shake out" during the test, as this may dislodge the EMG electrode placed on your body.

After the 5-minute interval has passed, you will perform another two maximum fingertip contractions against the force plate. Immediately after the contractions, you will climb for another 5 -minute interval or until failure.

Once you have reached failure or performed the 6 sets to completion, you will immediately perform the final maximal fingertip contractions.

This protocol will ensure that there is a difference between pre-fatigued and fatigued conditions, as well it gives researchers a quantifiable means of measuring fatigue.

Rating of perceived exertion will be recorded at the end of each interval during exercise using the Borg 6-20 scale.

Time Commitment. Total time for your participation is about 1.5 hours. This is broken into about 30 minutes for paperwork and habituation, then another hour for exercise and measurements.

Confidentiality. Personal information, private health information and data will be kept in a cabinet in a locked office. All data will be coded so that data sheets will not be identifiable.

Benefits. The results of this study can be generalized to the larger climbing population and will yield improvements in training protocols, safety during training, changes in contraction to relaxation ratios during climbing and improve the overall enjoyment of the sport. Moreover, identifying fatigue in muscles during climbing will benefit future studies focused on supplementation or those that require a baseline level of fatigue for comparison.

Compensation. There is no compensation for participating in this experiment.

Risks. There are risks to participating in this study. These include: fatigued or sore muscles and possible injury from falling from the treadwall. Foam matting will be placed below the treadwall to ensure safety in the event of an unexpected fall. Perceived exertion will be monitored throughout the testing. Subjects will be required to complete a health history form prior to participating which includes personal health information. This form will help screen potential health problems before the exercise. Subjects will be screened prior to the study for breathing disorders, precautions will be taken for their safety. There is no compensation available from MSU for injury.

Questions. Your decision whether or not to participate will not jeopardize your relationship with the Movement Sciences Laboratory. You are free to discontinue participation at any time without negative effects on your relationship with the MSU or the researchers. Privacy and confidentiality of data will not be breached. If you have any questions, please ask us.

Photos may be taken during the experiment. These photos may be used in presentation of data from this study.

If you have any additional questions later, Philip Ferrara (770-883-9177) or John Seifert (406-994-7154) will be happy to answer them. Additional questions about the rights of human subjects can be answered by the Chairman of the Institutional Review Board, Mark Quinn, (406) 994-4707.

Changes in Muscle Activity of the Forearms in Rock Climbers During Treadwall Climbing

Freedom of Consent

I have been given ample opportunity to read this document in its entirety and to ask questions which have been answered to my satisfaction. I hereby consent to become a participant in this study knowing the health risks involved and that I may withdraw my consent at any time, for any reason. I also understand that project personnel may screen me from this study for any reason deemed appropriate.

AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, ______________________________ *(name of subject),* agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: ____

Witness: ____

Investigator: ____

Date: ____ .

- ☐ **I consent to having my photographs reprinted in reports and presentations.**
- ☐ **I DO NOT consent to having my photographs reprinted in reports and presentations.**

APPENDIX D

STATISTICS SUMMARY TABLE

Variable		DF	F-value	p-value
REL FP	Group x Hand x Time	1, 1, 1	0.890	*0.354*
	Group x Hand	1, 1	8.23	***0.008***
	Group x Time	1, 1	1.099	*0.304*
	Hand x Time	1, 1	0.444	*0.511*
	Group	1	39.613	***0.001***
	Hand	1	2.2	*0.150*
	Time	1	0.762	*0.391*
Slope of FP	Group x Hand x Time	1, 1, 2	0.007	*0.993*
	Group x Hand	1, 1	0.005	*0.947*
	Group x Time	1, 2	4.223	*0.322*
	Hand x Time	1, 2	3.141	*0.054*
	Group	1	3.058	*0.088*
	Hand	1	1.367	*0.249*
	Time	2	1.285	*0.285*
ΔFP	Group x Hand	1, 1	0.47	*0.505*
	Group	1	16.057	***0.001***
	Hand	1	0.71	*0.415*
FDS ΔMF	Group x Hand	1, 1	0.082	*0.780*
	Group	1	15.145	***0.002***
	Hand	1	0.369	*0.555*
FDS ΔRMS	Group x Hand	1, 1	0.095	*0.763*
	Group	1	2.563	*0.135*
	Hand	1	1.723	*0.214*
Biceps ΔMF	Group x Hand	1, 1	2.505	*0.157*
	Group	1	2.620	*0.150*
	Hand	1	0.002	*0.966*
Biceps ΔRMS	Group x Hand	1, 1	0.929	*0.367*
	Group	1	0.112	*0.748*
	Hand	1	2.969	*0.129*
Triceps ΔMF	Group x Hand	1, 1	0.238	*0.643*
	Group	1	0.317	*0.594*
	Hand	1	3.081	*0.130*
Triceps ΔRMS	Group x Hand	1, 1	0.548	*0.470*
	Group	1	0.481	*0.753*
	Hand	1	0.913	*0.354*

APPENDIX E

MATLAB FORCE PLATE DATA ANALYSIS CODE

Force Plate Filtering

```
%READ IN DATA FILE
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);

plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000 %Hz - Sampling Freqeuncy
fn=sf/2; %Hz - Nyquist Frequency - 1/2 Sampling Frequency
[b,a]=butter(2,([8]/fn)); % Coefficients for filter -
Force_Crop_filtMVIC=filtfilt(b,a,Force_Crop); % Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filtMVIC);
Peak_MVICcrop = Force_Crop_filtMVIC(round(n*0.1):round(n*.9));
clear n
n = length(Peak_MVICcrop);
Peak_MVIC = Peak_MVICcrop(1:round(n*0.3125));
Avg_Peak_MVIC = mean(Peak_MVIC)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n


%READ IN DATA FILE 2
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);
```

```
plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt1=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt1);
Peak_Force1crop = Force_Crop_filt1(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force1crop);
Peak_Force1 = Peak_Force1crop(1:round(n*0.3125));
Avg_Peak_Force1 = mean(Peak_Force1)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n

%READ IN DATA FILE 3
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);

plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
```

```
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt2=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt2);
Peak_Force2crop = Force_Crop_filt2(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force2crop);
Peak_Force2 = Peak_Force2crop(1:round(n*0.3125));
Avg_Peak_Force2 = mean(Peak_Force2)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n

%READ IN DATA FILE 4
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);

plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt3=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt3);
Peak_Force3crop = Force_Crop_filt3(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force3crop);
Peak_Force3 = Peak_Force3crop(1:round(n*0.3125));
Avg_Peak_Force3 = mean(Peak_Force3)
```

```
clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n

%READ IN DATA FILE 5
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);

plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt4=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt4);
Peak_Force4crop = Force_Crop_filt4(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force4crop);
Peak_Force4 = Peak_Force4crop(1:round(n*0.3125));
Avg_Peak_Force4 = mean(Peak_Force4)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n

%READ IN DATA FILE 6
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);
```

```
plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt5=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt5);
Peak_Force5crop = Force_Crop_filt5(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force5crop);
Peak_Force5 = Peak_Force5crop(1:round(n*0.3125));
Avg_Peak_Force5 = mean(Peak_Force5)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b  n

%READ IN DATA FILE 7
[Forcefile,Forcepath]=uigetfile('.csv','Select the file containing the force data');
Forcefilepath=strcat(Forcepath,Forcefile);
[Forcedata]=readForce(Forcefilepath);

%create Z axis only
Force_Z=Forcedata(:,3);

plot(Force_Z);
%start
%stop
f=warndlg('Click on the graph where start and stop','Identify stop');
waitfor(f);

Force_Crop=Force_Z(start.DataIndex:stop.DataIndex,:)

%Filter
sf=1000%Hz - Sampling Freqeuncy
fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
```

```
[b,a]=butter(2,([8]/fn));% Coefficients for filter -
Force_Crop_filt6=filtfilt(b,a,Force_Crop);% Filter data forwarwards and
%backwards to eliminate phase shift

%get rid of first 10% and last 10%
n = length(Force_Crop_filt6);
Peak_Force6crop = Force_Crop_filt6(round(n*0.1):round(n*.9));
clear n
n = length(Peak_Force6crop);
Peak_Force6 = Peak_Force6crop(1:round(n*0.3125));
Avg_Peak_Force6 = mean(Peak_Force6)

clear Forcefile Forcepath Forcefilepath Force_Z f Force_Crop sf fn a b n

%%% Naming %%%
save('/Users/Philip/Desktop/Subject_X_D.mat');

%% Loop for Finding Filter Cut Off%%
%%for i=1:20
   %%sf=1000%Hz - Sampling Freqeuncy
   %%fn=sf/2;%Hz - Nyquist Frequency - 1/2 Sampling Frequency
   %%[b,a]=butter(2,([i 21]/fn));% Coefficients for filter -
   %%Force_Crop_filt(:,i)=filtfilt(b,a,Force_Crop); % Filter data forwarwards and
%backwards to eliminate phase shift %
%%end %%
```

Normalize and Plot Data

```
load('/Users/Philip/Desktop/Subject_1_NONDOM.mat');


% find the longest length of Cropped_Force_Data
time(:,1) = length(Peak_Force1crop);
time(:,2) = length(Peak_Force2crop);
time(:,3) = length(Peak_Force3crop);
time(:,4) = length(Peak_Force4crop);
time(:,5) = length(Peak_Force5crop);
time(:,6) = length(Peak_Force6crop);
timemax = max(time);

Avg_Peak_MVIC_array = Avg_Peak_MVIC .* ones(timemax,1);

% Plots Cropped Data with Avg MVIC line
figure;
```

```
plot(Peak_MVIC)
hold on;
plot(Avg_Peak_MVIC_array);
plot(Peak_Force1crop);
plot(Peak_Force2crop);
plot(Peak_Force3crop);
plot(Peak_Force4crop);
plot(Peak_Force5crop);
plot(Peak_Force6crop);

% Normalized
Norm_Force1 = Peak_Force1crop / Avg_Peak_MVIC;
Norm_Force2 = Peak_Force2crop / Avg_Peak_MVIC;
Norm_Force3 = Peak_Force3crop / Avg_Peak_MVIC;
Norm_Force4 = Peak_Force4crop / Avg_Peak_MVIC;
Norm_Force5 = Peak_Force5crop / Avg_Peak_MVIC;
Norm_Force6 = Peak_Force6crop / Avg_Peak_MVIC;


Linear1 = fitlm([1:1:length(Norm_Force1)],Norm_Force1);
Linear2 = fitlm([1:1:length(Norm_Force2)],Norm_Force2);
Linear3 = fitlm([1:1:length(Norm_Force3)],Norm_Force3);
Linear4 = fitlm([1:1:length(Norm_Force4)],Norm_Force4);
Linear5 = fitlm([1:1:length(Norm_Force5)],Norm_Force5);
Linear6 = fitlm([1:1:length(Norm_Force6)],Norm_Force6);


figure;
plot(Norm_Force1);
hold on;
plot(Linear1);
plot(Norm_Force2);
plot(Linear2);
plot(Norm_Force3);
plot(Linear3);
plot(Norm_Force4);
plot(Linear4);
plot(Norm_Force5);
plot(Linear5);
plot(Norm_Force6);
plot(Linear6);

%%% Naming Convention %%%
save('/Users/Philip/Desktop/Subject_X_D_NormLinearPlot.mat');
```