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**THE RELATIVE IMPORTANCE OF FOUR MUSCLE GROUPS FOR INDOOR ROCK  
CLIMBING PERFORMANCE**

**BY**

**MICHAEL R. DEYHLE**

Submitted in Partial Fulfillment of the  
Requirements for the Degree of

**Master of Science**

**Physical Education**

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**The Relative Importance of Four Muscle Groups for Indoor Rock Climbing  
Performance**

**By**

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**ABSTRACT**

The purpose of this study was to determine which muscle groups are most important for rock climbing. Eleven skilled male climbers were familiarized with an indoor climbing route before 5 separate days of testing. On testing days, subjects were randomly assigned a pre-fatiguing exercise designed to specifically target the digit flexors (DF), shoulder adductors (SA), elbow flexors (EF), or lumbar flexors (LF) or control climb with no pre-fatigue. Immediately after the pre-fatiguing exercise the subject climbed the route as far as possible without rest and until failure. The number of climbing moves was recorded for each climb. Surface electromyography of the target muscle was recorded during the pre-fatiguing exercises. Time was recorded from the start of pre-fatigue to the end of the climbing bout. Significantly fewer climbing moves compared to the control climb were completed after pre-fatigue of the DF and EF (50%

$\pm 18\%$  and  $78\% \pm 22\%$  of control) ( $p < 0.05$ ). Fewer moves were completed following pre-fatigue of the LF and SA ( $89\% \pm 17\%$  and  $92\% \pm 19\%$  of control), but these results were not significant ( $p > 0.05$ ). EMG median frequency for each muscle was reduced from beginning to end of each pre-fatiguing exercise. No significant differences were found among transit times (between end of pre-fatigue and start of route) ( $p > 0.5$ ). These results suggest that among the muscle groups studied in men, the order of importance from most to least for rock climbing  $40^\circ$  overhanging terrain is DF, EF, LF, and SA.

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## SYMBOLS / ABBREVIATIONS

±: plus or minus

ANOVA: analysis of variance

%BF: body fat percentage

BR: brachioradialis

DF: digit flexor

EF: elbow flexor

EMG: electromyography

FDS: flexor digitorum superficialis

IS: Infraspinatus

kg : kilogram

LF: lumbar flexor

LD: latissimus dorsi

MVC: maximum voluntary contraction

PM: pectoralis major

PORH: post occlusive reactive hyperemia

RA: rectus abdominis

SA: shoulder adductor

VO<sub>2</sub>: rate of oxygen consumption

VO<sub>2max</sub>: maximal rate of oxygen consumption



## CHAPTER 1

### *Introduction*

Traditional rock climbing uses temporary protection that the climber wedges into cracks and spaces in the rock face as she or he progresses up the rock. The rope is clipped into the temporary protection to help catch the climber in case of a fall. From traditional climbing, sport climbing evolved. In sport climbing the temporary protection is replaced by permanent protection bolted into the rock face. The element of danger of a catastrophic fall is thought to be greatly reduced with the use of the permanent protection (1). Therefore, in sport climbing more emphasis is often placed on the difficulty of the rock climb compared to traditional climbing, and climbers often push the difficulty of climbing to a greater degree. Together with the birth of sport climbing and dramatic increase in indoor rock climbing gyms (8) and worldwide climbing competitions (9, 11) rock climbing is increasingly popular and is becoming recognized as an athletic sport separate from traditional mountaineering and mountain climbing of the past. As with any athletic sport, training is a vital force leading to success among competitors. Training to improve climbing performance is widely used among climbers (5, 7). More research is needed, however, to further elucidate the demands that climbing places on the athlete so trainers, coaches and climbing enthusiasts can more effectively design and implement training programs for improved rock climbing performance.

### *Purpose of the Study*

The purpose of this study is to determine the relative importance of four muscle groups for the performance of indoor rock climbing on steep overhanging ( $40^{\circ}$  from vertical) terrain in a population of skilled and experienced male rock climbers. The scientific approach of the study will be to equally and individually reduce each muscle group's ability to do work by imposing pre-fatiguing isometric exercise at 25% of MVC immediately before rock climbing. Fatigue criteria will be met when the subject cannot hold the required joint angle or body position for five seconds or longer. Rock climbing performance is expected to be reduced following pre-fatigue of each muscle group. The degree of performance decrement (relative to the control climb), therefore, will be inversely proportional to that muscle group's importance for rock climbing performance.

### *Hypothesis*

In this study the following hypotheses will be tested:

1. Climbing performance, as measured by the number of moves (hand holds reached) before falling off of the climbing route, will be negatively impacted immediately following isometric contractions to failure of muscles involved in finger flexion, elbow flexion, shoulder adduction and lumbar flexion individually.

Rationale: studies show that strength and endurance of the fingers and grip (2, 3, 6, 8), shoulder girdle, and elbow flexors (2, 3, 8) is positively correlated with climbing ability. No study has shown muscle function of the abdominals to be correlated with climbing ability, however, their role remains in the present hypothesis because it is biomechanically reasonable to assume they are active and contribute to climbing locomotion and stability.

2. The magnitude of rock climbing performance decrement will be greatest following isometric fatigue of the finger flexors and will decrease in the following order; isometric elbow flexion, isometric shoulder adduction, and lastly isometric trunk flexion.

Rationale: fatigue of the finger flexors is expected to have the greatest impact on climbing performance because climbing itself has been shown to result in reduced grip strength and endurance for up to 20 minutes (11).

Electromyographic data during simulated climbing moves shows that the Flexor digitorum superficialis (FDS), a finger flexor, is highly activated (69% of MVC) (4). Pre-fatiguing exercise of the elbow flexors is expected to have the next greatest decrement on climbing performance because activation of the brachioradialis during simulated climbing moves closely followed that of the FDS (67% of MVC) (4). Fatigue of the shoulder adductors is expected to have the third greatest impact on climbing performance because while studies have correlated muscle function of the shoulder adductors to climbing performance

(3, 8) no study has shown a direct relationship. Lastly, fatiguing the lumbar flexors is expected to have the smallest impact on climbing performance because studies have failed to correlate function of this muscle group to climbing performance (2, 3).

### *Scope of the Study*

Eleven male subjects from the Albuquerque community volunteered to participate in this study. Prior to subject recruitment, the Institutional Review Board of the University of New Mexico approved the study. All subjects were given a detailed description of what their involvement in the study entailed prior to participating. All subjects also completed an informed consent, health history questionnaire, and climbing history questionnaire prior to testing. To meet inclusion eligibility, subjects were between the ages of 18 and 44 years, and have a minimum red point rock climbing ability (ability to climb a route with prior practice) of 5.12 on the Yosemite decimal system (YDS), and be able to complete the indoor rock climbing route that was set for use in this study. Interested participants were excluded if they had any known neurological disease, musculoskeletal injury or disease that would be aggravated by the study interventions or would hinder performance of rock climbing.

The primary dependent variable measured was moves completed on the rock climbing route before falling. Maximal force output was measured during isometric MVC on the dominant side for hand grip, shoulder adduction, elbow flexion, and lumbar flexion. To characterize body composition, skinfold thickness was measured at three sites (chest, abdomen and thigh). Surface electromyography of target muscles was

recorded during all pre-fatiguing exercises. Duration of pre-fatiguing exercises, climbing bouts, and transit time (between end of pre-fatiguing exercise to start of climb) was measured. Rating of perceived exertion was measured during pre-fatiguing exercise and after completion of the climbing bout to exhaustion. Using a climbing history questionnaire, subject-reported current and best climbing ability rating was gathered.

### *Limitations*

This study was subject to the following limitations:

1. Subjects were asked to refrain from exercise and climbing 24 hours before participating in the study, but pre-participation physical activity was not quantified.
2. Only men were included in this study. Subject recruitment efforts targeted both men and women but too few women agreed to participate to have an equal sample.
3. Because of the inherent variability of rock climbing terrain, results from this study can only be generalized to rock climbing done on overhanging (40° from vertical) terrain on an indoor climbing wall.
4. Because this study required several visits on separate days, every effort was made to complete each subject's data collection in a timely manner over the time possible to account for any training or de-training effects. However, days between visits did vary considerably among some subjects.

### *Assumptions*

The following assumptions were made in this study:

1. Participants followed all pretest guidelines.
2. Climbing ability was honestly reported.
3. Health history was honestly reported.
4. RPE was honestly reported.
5. Subjects gave maximal effort during each trial.

### *Significance of the Study*

Rock climbers report devoting as many as twenty hours per week to training for rock climbing (7). Climbers also report doing a variety of training types including, endurance, resistance and coordination exercises (5). While training to improve rock climbing performance is commonplace, little research has been done to find out what muscles or muscle groups are most important during rock climbing. This information would be useful to people interested in designing more efficient training programs for climbing by targeting those most important muscle groups. This study is significant because it will help provide information about the relative importance of specific muscle groups for rock climbing.

### *Definitions*

*Adduction* - used to describe the movement of a joint toward the midline of the body

*Anthropometry* - the study of quantifying the dimensions and components of the human body.

*Ape Index* - the mathematical difference of arm span and body height.

*Dynamometry* - the science of measuring mechanical force.

*Flexion* - a description of joint movement when the angle of the joint decreases

*Lactate* - the three-carbon product of incomplete oxidation of glucose. Blood concentration of lactate is directly related to exercise intensity

*Red point* - A characterization of rock climbing in which the climber completes a climbing route on lead without falling or resting on the rope after having prior experience attempting that specific route.

*Sport climbing* - A style of lead climbing in which the climber use permanent protection to anchor the safety rope as he or she progresses up the climb.

*Stadiometer* - a device used to measure body height.

*Traditional climbing* - a style of lead climbing in which the climber places temporary protection into spaces in the rock for anchoring the safety rope as he or she ascends the climb.

*Yosemite Decimal System* - a grading system used to denote the difficulty of walks, hikes and rock climbs.

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## **CHAPTER 2**

### **Review of Related Literature**

#### Introduction

Rock climbing has the reputation of being a dangerous, death-defying activity. However, when the proper safety equipment is used and safety procedures are followed, rock climbing is a relatively safe sport. In traditional climbing, the climber places temporary safety equipment into cracks and spaces in the rock as she or he progresses up the climb. The rope, to which the climber is attached, is clipped into the safety gear to help catch the climber in case of a fall. Sport climbing evolved from traditional climbing and uses permanent safety gear that is bolted into the rock. Sport climbing, because of the permanently secured safety gear, is thought by many to be even safer than traditional climbing (11). Because of the increased sense of safety sport climbers often push themselves to complete more physically challenging rock climbs.

Since there has been a large increase in sport climbing popularity since the 1980's, the difficulty of rock climbs completed has increased steadily (11). The difficulty of rock climbs are rated subjectively using grading systems and consensus among climbers. Many different grading systems exist throughout the world (11, 17, 27) but the Yosemite decimal system (YDS) is the most commonly used in the United States (11). The YDS consists of classes 1-5 to describe the difficulty of the terrain to travel. Class 1 is walking. Terrain that falls into classes 2-4 get progressively steeper and the use of hands and arms increases. Class 5 on the YDS is very steep terrain and

considered technical climbing. These technical rock climbs within class 5 progresses in difficulty from 5.0 to 5.15. Climbs 5.10 and harder are further divided with the addition a-d difficulty ratings. For example, 5.11d is more challenging than 5.11b.

Since the birth of sport climbing and coinciding with the steady increase in the difficulty of rock climbs being completed, the use of indoor rock climbing gyms (20) has greatly increased and climbing as a world-wide competitive sport is gaining interest and participants (23,24). As with any competitive athletic sport, training to improve performance is commonplace in the sport of rock climbing (16, 18). Research that elucidates the physiological stresses of and adaptations to climbing provides vital information for designing more effective training programs to improve climbing performance. This review will examine the literature on the physiological demands and response to climbing as well as literature highlighting adaptations, characteristics, and strategies that may improve climbing performance.

### Physiological responses to climbing

#### *Oxygen Consumption*

For climbs lasting about eighty seconds, energy is supplied by primarily aerobic sources (39.7 %) (2). The first studies to measure oxygen consumption during climbing used Douglas bags to collect expired gases from the subjects (3, 19). These two studies found nearly identical average  $\text{VO}_2$  data of 24.9ml/kg/min (3,17) on routes of similar difficulty. One of these studies measured  $\text{VO}_{2\text{max}}$  on both the treadmill and an upper-body pull down ergometer as well as  $\text{VO}_2$  during climbing on two routes of the same

difficulty.  $\text{VO}_2$  achieved during climbing of the two routes was very close to the maximal  $\text{VO}_{2\text{max}}$  attained during the pull down ergometer test but much less than  $\text{VO}_2$  attained during the treadmill test. Because climbing  $\text{VO}_2$  was similar to  $\text{VO}_{2\text{max}}$  attained during a more mode-specific ergometry method, this suggests that climbing may elicit very high percentages of mode specific  $\text{VO}_{2\text{max}}$ . This has been confirmed more recently (4). This study found that  $\text{VO}_2$  during outdoor climbing reached a significant percentage (75%) of climbing  $\text{VO}_{2\text{max}}$  measured using a discontinuous protocol on a vertical climbing ergometer.

Two variables that increase  $\text{VO}_2$  during climbing are overhanging terrain (3, 10, 19) and vertical displacement (10). A route is overhanging when it is steeper than vertical. Energy expenditure per unit distance covered increases significantly at angles greater than vertical (22). Geus and coworkers used four routes of the same technical difficulty. The climb that elicited the greatest  $\text{VO}_2$  was overhanging with vertical displacement (climbers went up the wall) while the climb that elicited the lowest  $\text{VO}_2$  was non-overhanging without vertical displacement (climbers traveled laterally). The two other climbs elicited a relatively moderate  $\text{VO}_2$  (10). The results suggest that vertical displacement and overhanging terrain independently increase physiological demand of climbing.

### *Heart rate*

During climbing, heart rates for a given  $\text{VO}_2$  are greater than would be predicted (3, 19). The reason for the disproportionate rise in heart rate relative to  $\text{VO}_2$  may be because of the extensive use of isometric muscle action during climbing (3). Research

shows that isometric contractions can result in a disproportionate rise in heart rate (15). Another possible explanation is that heart rate may be elevated because of anxiety and fear during climbing (27). This is a less likely explanation because this phenomenon of augmented heart rate has been seen in highly controlled and safe indoor climbing environments to which the subjects would be accustomed (3, 19).

### *Climbing Movement Efficiency*

Efficient climbing movement is likely to improve rock climbing performance. Improved climbing efficiency would, theoretically, delay the onset of fatigue and allow the climber to make harder climbing moves as a greater percentage of energy is directed to climbing progress. Research shows that after nine times practicing the same climbing route over a period of ten weeks, climbers were able to complete a route with significantly less total energy expenditure (7). This suggests that the climbers may have improved their climbing efficiency as they became more familiar with the route. Another study showed that energy expenditure on a climbing route was significantly lower for the elite climber compared to the recreational climber showing that elite climbers can climb more efficiently (2). Other factors may be at play to explain why expert climbers can climb harder and longer climbers. Expert climbers in a time to exhaustion test on a climbing ergometer lasted significantly longer than elite (slightly less skilled) climbers (6). Climbing efficiency cannot explain the difference in time to exhaustion because  $VO_2$  was not different between the groups. A possible explanation for the difference in time to exhaustion is that a higher  $VO_2$  at metabolic threshold during arm ergometry has been shown to be predictive of climbing performance (17). While it may be tempting to attribute the above results to improved climbing efficiency

no study has directly evaluated this. More research is needed in this area perhaps by evaluating climbing biomechanics.

### *Muscle Activation*

Koukoubis and coworkers measured muscle activation of the arms during simulated rock climbing moves with surface electromyography (EMG) (14). The most active of the muscle studied was the flexor digitorum superficialis (FDS) that was firing at 69% of that of MVC. The second most active muscle was the brachioradialis (BR) that fired at 67% of MVC. The BR was much more active than the biceps brachii (another elbow flexor) probably because of the pronated forearm position most commonly used in climbing.

Watts and coworkers (26) measured EMG of the forearm muscles during maximal grip dynamometry and rock climbing with several different hand positions. The results showed that EMG amplitude during climbing was between 126 and 222% higher than during maximal grip dynamometry. Grip forces during climbing were not measured, but amplitudes as large as were measured would predict forces greater than 980 Newtons, a force greater than the weight of the heaviest subject in the study. These results show that muscle activation of the forearm muscles differ significantly between climbing and grip dynamometry.

### Recovery methods

Rock climbing itself (25) and simulated rock climbing moves (1) can result in fatigue and temporarily reduced performance. Accelerated recovery between rock climbs can be useful to improve subsequent rock climbing performance during sessions

when rest time may be minimal or insufficient. This may have particular application to the competitive climber between heats in a competition. Two interventions appear to be useful to accelerate and maximize recovery and maintain performance during subsequent rock climbs. These are active recovery and arm/hand cooling.

Performing a low intensity exercise between bouts of climbing has been shown to reduce blood lactate compared to passive recovery (5, 21). This has implications for improved recovery because blood lactate concentration is negatively correlated with recovery of grip strength following rock climbing (25). Arm/ hand cooling between sets of simulated rock climbing moves preserves subsequent performance of simulated climbing moves better than passive recovery (1). Heyman and coworkers showed that hand/forearm cooling and active recovery independently preserved subsequent climbing performance over passive recovery or electromyostimulation (9).

### Anthropometry

Anthropometric characteristics such as low percent body fat (%BF) and high arm span to height ratio (Ape index) are often thought to be advantageous for better rock climbing performance. This section will examine the literature on this topic.

#### *Body fat percentage*

Highly trained and competitive climbers tend to be very lean (19, 23, 24, 26). Men and women semifinalists of an international World Cup Sport Climbing Competition had an average %BF of 4.7 and 10.7, respectively (24). Among the same competitors who became finalists no significant differences in %BF were found.

However, significantly lower fat free mass was found in men and women finalists and these athletes also had significantly lower body mass than women semifinalist. This study also found that lower %BF and high relative grip strength (kg force/ kg body weight) was predictive of greater rock climbing performance. Other studies have found that low %BF together with other variables is predictive of rock climbing performance. Mermier and coworkers found that together with measurements of muscular strength and power and %BF explained the largest percentage (37%) of variability in climbing performance (18). Another study found that %BF when grouped with other anthropometric and muscular strength variables helped explain a similar percentage (38%) of variability in climbing performance (17).

The literature appears to support the thought that low %BF may be advantageous for climbing performance perhaps because excess body fat would add to the climber's body weight and increase the work required to complete rock climbs.

### *Ape Index*

Ape Index can be calculated by subtracting a person's height from his arm span. Having a positive Ape Index (longer arm span than height) has been hypothesized to be a positive attribute for climbing performance because it would allow the climber to maintain a lower center of gravity (low body height) while being able to reach further for holds (long arms). The climbing literature on Ape Index is mixed. One study found that young competitive rock climbers did have a greater Ape Index than their age-matched controls (1.02 v.s 0.95) (23). While this study may suggest that these young athletes self-selected climbing because they possessed predisposing advantages such as

a higher Ape Index, another study showed that Ape Index has no significant correlation with climbing ability (18). To date, the only study showing that Ape Index is related to climbing ability is contrary to the commonly held opinion that a greater Ape Index would be positively related to climbing ability. This study showed that a larger Ape Index was inversely related to rock climbing ability (17). Having shorter arms tends to reduce Ape Index but this may pose a biomechanical advantage by having reduced length of mechanical lever arms in the limbs allowing for greater force generation for a given muscle mass. More research is needed to resolve the conflicting literature on Ape Index and climbing.

### Muscular Strength and Endurance

High strength and endurance of muscles involved in climbing locomotion, especially when expressed relative to body mass, appear to support high-level rock climbing (12,13,20). This section will examine the literature on the topic.

#### *Grip strength*

Most climbing literature looking at muscular characteristics has focused on the forearm musculature. This is likely because, anecdotally, the forearm musculature is the most stressed muscle group during more difficult climbing routes, and that failure to maintain grip with the hold is the most commonly reported reason for falling during climbing bouts to failure (25). Much of the literature uses handgrip dynamometry as the method for measuring handgrip strength and endurance. While handgrip dynamometry is not entirely biomechanically (11) or electromyographically (26)



climbing specific, skilled climbers do show greater relative force (force/ body weight) than non-climbers (13) and less skilled climbers (12).

Other methods of measuring grip strength have been implemented that more closely resemble a typical rock climbing grip. Wall and colleagues (20) used a system of pulleys, cables, force transducers and a wooden simulated climbing hold to measure climbing specific grip strength. In this study, the climber held the simulated hand hold with her four fingers while the researcher pulled on a lever which slowly generated tension that the climber was required to match with her grip. This continued until the force was too great for her to match. This method was more climbing specific than dynamometry because of the hand position and the nature of the forces generated. The hand position was more climbing specific because only the four fingers (without thumb) were involved in the exercise. Most climbing grips do not use the thumb in the way that grip dynamometry does (11). For this test, forces placed on the climbers' hand was more specific to climbing than grip dynamometry because, like during climbing, the subject was required to match the force placed on the fingers to resist opening of the hand. Grip dynamometry requires that the subject squeeze the grip in more of a concentric manner. Using this method of grip strength measurement, the researchers found that grip strength relative to body mass was correlated with climbing performance ( $r$ -value = .665 right hand,  $r$  = .631 left hand) (20). Magiera and colleagues also used a more climbing specific method to measure grip strength and endurance by measuring force generated from the subjects' four fingers (without thumb). Together with five other variables in a canonical analysis, finger strength and finger endurance helped explain 77% of the variance in climbing performance (17).

A study by Watts and coworkers highlighted the importance of the forearm musculature for rock climbing more directly by measuring grip strength and endurance immediately following indoor rock climbing to the point of a fall (25). Relative to pre-climbing values, maximal handgrip strength was reduced one minute after climbing and five minutes after climbing but was restored to normal ten minutes after climbing. Grip endurance was measured by the duration that the subject could maintain 70% of maximal strength on the grip dynamometer. Grip endurance time was significantly reduced immediately after and remained lower than pre-climbing values 20 minutes after climbing.

Ferguson and coworkers studied the handgrip endurance in rock climbers and untrained sedentary individuals (8). They found during sustained isometric gripping exercise there was no significant difference in time to fatigue between the climbers and non-climbers. During rhythmic contract/relax hand gripping the time to exhaustion of the climbers was twice that of the non-climbers. In this study vascular conductance was also shown to be significantly higher in the climber group immediately after sustained isometric exercise and arterial occlusion compared to non-climbers. This suggests that improved endothelial function and/or reduced muscle sympathetic nerve activity in the climbers was a contributing factor for the longer time to fatigue during the climbing specific (contract/relax) exercise.

#### *Shoulder Strength/Endurance*

Among elite competitive climbers, strength and endurance of the shoulder girdle muscles is thought to be an important factor determining climbing performance (24).

This opinion has been supported in two studies using complex statistics to explain variability in climbing ability. Mermier and coworkers found that upper body power and shoulder strength and endurance were among the variables that explained the most variability (37%) in climbing performance (18). Another study also found that among seven variables endurance of the shoulder girdle muscles, as measured by  $\dot{V}O_2$  at lactate threshold during arm ergometry, explained 77% of the variance in climbing ability (17).

Other studies have shown that elite climbers have higher strength and endurance of the shoulder girdle muscles than recreational and/or non-climbers. Elite male climbers can do more consecutive pull-ups and can hold a bent arm hang (isometric pull-up position 90 degrees at elbows) for longer than male recreational and non-climbers (13). Among female elite, recreational and non-climbers, no significant differences were found in these two tests (12). However, maximal strength of a single arm pull-up action (single arm lock-off) in expert female climbers is greater than in intermediate and moderately skilled female climbers (20).

Together these studies suggest that strength and endurance of the shoulder girdle muscles are important for climbing performance. However, the methods used to measure the performance of the shoulder muscles often do not adequately isolate the muscles of the shoulder. Performance of the pull-up, bent arm hang, and upper-body ergometry use the shoulder girdle coupled with elbow flexion. To date, no research has evaluated the strength and endurance of the shoulder muscles independent of the muscles involved in elbow flexion.

### Conclusion

Clearly, the available literature shows that rock climbing is a complex sport. The studies that were most successful in explaining climbing variability showed that no one variable can explain or predict rock climbing performance or ability (17,18). These two studies still left about one third of the variance in climbing performance unexplained. More research is needed to improve our understanding of the stresses that climbing places on climbers, especially those attempting difficult climbing routes. One approach may be to look at other muscle groups similar in detail to that shown in the available literature for the forearm musculature in climbers and climbing. This information is needed for climbing coaches and climbing enthusiasts to design better training strategies.

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## **CHAPTER 3**

### **RESEARCH MANUSCRIPT**

This chapter presents a research manuscript, entitled “The Relative importance of Four Muscle Groups for Indoor Rock Climbing Performance”. This manuscript will be submitted to the Journal of Strength and Conditioning Research. The manuscript is authored by Michael Deyhle, Taryn Cadez-Schmidt, Hung Sheng-Hsu, Timy Fairfield, and Christine M. Mermier. The manuscript follows the formatting style of the journal. References are at the end of the chapter.

**Title:** The Relative Importance of Four Muscle Groups for Indoor Rock Climbing Performance

**Running Head:** Four muscle groups in rock climbing

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**The Relative Importance of Four Muscle Groups for Indoor Rock Climbing  
Performance**

## ABSTRACT

The purpose of this study was to determine which muscle groups are most important for rock climbing. Eleven skilled male climbers were familiarized with an indoor climbing route before five separate days of testing. On testing days, subjects were randomly assigned a pre-fatiguing exercise designed to specifically target the digit flexors (DF), shoulder adductors (SA), elbow flexors (EF), or lumbar flexors (LF) or control climb with no pre-fatigue. Immediately after the pre-fatiguing exercise the subject climbed the route as far as possible without rest and until failure. The number of climbing moves was recorded for each climb. Surface electromyography of the target muscle was recorded during the pre-fatiguing exercises. Time was recorded from the start of pre-fatigue to the end of the climbing bout. Significantly fewer climbing moves compared to the control climb were completed after pre-fatigue of the DF and EF ( $50\% \pm 18\%$  and  $78\% \pm 22\%$  of control) ( $p < 0.05$ ). Fewer moves were completed following pre-fatigue of the LF and SA ( $89\% \pm 17\%$  and  $92\% \pm 19\%$  of control), but these results were not significant ( $p > 0.05$ ). EMG median frequency for each muscle was reduced from beginning to end of each pre-fatiguing exercise. No significant differences were found among transit times (between end of pre-fatigue and start of route) ( $p > 0.5$ ). These results suggest that among the muscle groups studied in men, the order of importance from most to least for rock climbing 40° overhanging terrain is DF, EF, LF, and SA.

**KEY WORDS** pre-fatigue, electromyography, median frequency, forearm

## INTRODUCTION

Rock climbing as a competitive sport draws contestants from around the world (23) of both genders (23) and various age groups (22). Rock climbing competitions usually take place in indoor climbing gymnasiums (23,22). The number of indoor rock climbing gyms as well as the number of people getting involved in rock climbing recreationally is on the rise (20).

The goal among competitive climbers and climbing enthusiasts alike is often to increase one's rock climbing prowess so she or he may be able to climb more challenging rock climbs. Training is crucial to help climbers maximize their potential and ability to successfully complete harder rock climbs. Reportedly, climbers spend up to twenty hours per week training (16) and use a variety of resistance, endurance, and coordination exercises (14). Despite training being a common practice among climbers, little research is available on the topic.

Climbing performance and ability have been positively correlated with grip strength (10,20,23) and finger strength (9,10,15) as well as strength and endurance of the shoulder girdle as measured by number of pull ups (10), bent arm hang time (10,16) and single-arm pulling strength (20). Studies that were most successful in explaining variance in climbing performance confirmed that variables related to power, strength and endurance of the upper body are among the most important to predict climbing ability (15,16).

To date, no study has looked at performance characteristics of multiple muscle groups of the upper body in isolation in relation to climbing performance. The purpose of this study was to determine the relative importance of the muscle groups involved in

digit flexion (DF), shoulder adduction, (SA), elbow flexion (EF), and lumbar flexion (LF). It was hypothesized that the DF muscle group will show primary importance followed by the EF, SA, and LF muscle groups, respectively

## **METHODS**

### **Experimental approach to the problem**

This study was designed to equally and individually reduce each muscle group's ability to do work by imposing isolated pre-fatiguing exercise at 25% of maximal voluntary contraction (MVC) immediately before one bout of rock climbing to failure. This low percentage of MVC was chosen because research shows that recovery time after fatiguing contractions is inversely related to the relative intensity of the contraction used (18). This approach was expected to answer the research question because each pre-fatiguing exercise was expected to reduce climbing performance to a degree inversely proportional to that muscle group's importance to rock climbing. Each pre-fatiguing exercise was randomly assigned over the course of five separate days. A control, with no pre-fatiguing exercise, was also randomly assigned. Climbing performance, as measured by number of hand moves completed was measured for each trial. All trials were performed on the same wall using the same moves (Figure 4.). The climbing sequence (hand movement strategy) was the same for each subject and every trial.

### **Subjects**

Eleven advanced male rock climbers with an average climbing history of  $3.9 \pm 2.5$  years climbing experience and an average climbing ability of 5.12b on the Yosemite

Decimal System (YDS), volunteered to participate in this study. The study protocol was approved by the Institutional Review Board. Prior to testing, subjects signed informed consent and HIPPA forms, and filled out climbing and health history questionnaires. In order to participate in this study, volunteers were required to be able to red point rock climbs rated at least 5.12a difficulty on the YDS, which means they could complete the rock climb after having prior practice climbing that specific rock climb. The subject's climbing ability was self-reported. Potential subjects were also required to be able to climb the specific route used in the study from start to finish without rest. Volunteers were excluded if they were not between the ages of 18 and 44 years, had been diagnosed with cardiovascular, or neurological diseases, or had any injury or limitation that would be aggravated by the study protocol or hinder performance of rock climbing.

### **Anthropometry**

Height and weight were measured using a calibrated mechanical balance scale and stadiometer. A t-shirt, shorts and no shoes were worn during weight and height measurements. Skinfold thickness was measured using a Lange caliper (Cambridge Scientific Industries, Columbia, Maryland USA) at the chest, abdomen and thigh for body composition estimation. Two measurements within 2 mm of one another for each site were averaged. The sum of the averaged measurements was taken and used to estimate body density (12). Body fat percentage was estimated using the equation described by Brozek (4). Table 1 shows subject anthropometric data.

**Table 1 Descriptive statistics. Standard deviation (SD).**

	Age (years)	Height (cm)	Weight (kg)	% Body fat	BMI (kg/m <sup>2</sup> )
Mean (SD)	27.7 (3.8)	175 (7.4)	68.11 (6.6)	7.66 (2.2)	22.22 (2.1)
Range	21-33	162.6 -187.5	58.3 – 77.8	4.42 – 12.8	17.8 – 25.8

### **Muscular strength**

MVCs were performed for digit flexion, shoulder adduction, elbow flexion and trunk flexion (on dominant side where applicable). Peak force during MVC was measured using a Rolyan hydraulic hand dynamometer (Rolyan, Germantown, Wisconsin, USA) for digit flexion, and a back strength dynamometer (Takei Scientific Instruments CO., LTD., Japan) for all other MVCs. Each MVC was done in triplicate with a one-minute rest between attempts. The greatest of the attempts was used (Table 2). Each MVC protocol was designed to isolate the muscle group of interest. The following bullet points describe the protocol used for each MVC test.

- Digit Flexion MVC- The handgrip dynamometer was adjusted for each subject so that the middle phalanx lined up with the handle (16). The subject was instructed to hold the dynamometer with a straight arm with arm hanging at his side and slowly generate force over a three second period.
- Shoulder adduction MVC- Subjects sat in a chair with shoulder abducted at 90 degrees on the frontal plain. This joint angle was chosen for ease of joint angular measurement. A padded Velcro strap was wrapped around the upper arm just proximal of the elbow joint. A rope was attached to the Velcro strap at one end and to the dynamometer at the other end that was hanging directly over the

- subject's elbow. The subject was instructed to slowly pull downward on the rope over a three second period against the dynamometer. (Figure 1).
- **Elbow Flexion MVC-** Subjects were seated in a chair with elbows resting on a padded bench just in front of the subject's chest. A rope was attached to the subject's wrist with a Velcro strap. The other end of the rope was attached to the back strength dynamometer that was fixed at ground level in front the subject. With a pronated wrist and elbow at  $90^{\circ}$ , the subject generated as much isometric tension with the elbow flexors as possible over a 3-second contraction (Figure 2). The joint angle was chosen for ease of joint angular measurement.
  - **Lumbar Flexion MVC –** Subjects started resting supinated on a mat. A nylon sling was placed around the shoulders of the subject like backpack straps. Attached to the sling was a rope which was attached to the back strength dynamometer. Subjects then did a half sit-up as described in the Young Men's Christian Association's (YMCA) fitness assessment protocol (11). Enough slack was in the system to allow the subject to reach the prescribed half sit-up range of motion (3.5" horizontal displacement). The subject then generated as much isometric force against the dynamometry system as possible at the end of the half sit-up range of motion (Figure 3).

**Table 2. Dynamometry values for handgrip (GD), shoulder adduction (SAD), elbow flexion (EFD), and lumbar flexion (LFD). Values are presented as absolute force in kilograms (kg<sub>f</sub>) and in relative force per kilogram of body mass (/kg). Standard deviation (SD).**

	GD (kg <sub>f</sub> )	GD/kg	SAD (kg <sub>f</sub> )	SAD/kg	EFD (kg <sub>f</sub> )	EFD/kg	LFD (kg <sub>f</sub> )	LFD/kg
Mean	55.3	0.8	47.5	0.7	29.3	0.4	30.6	0.5
(SD)	(13.0)	(0.1)	(5.3)	(0.5)	(2.7)	(0.04)	(9.3)	(0.1)
Range	44-90	0.7-1.2	34-58	0.6-0.8	26-34	0.4-0.5	20-51	0.3-0.7

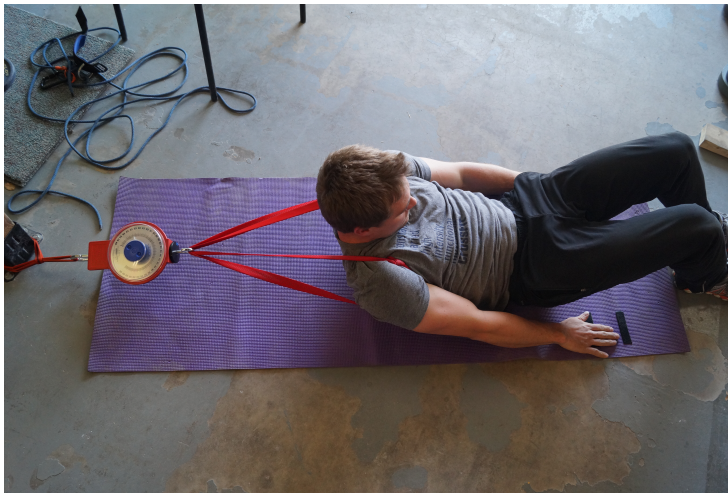


**Figure 1. Shoulder adduction dynamometry**



**Figure 2. Elbow flexion dynamometry (forearm pronated).**





**Figure 3. Lumbar flexion dynamometry**

### **Climbing Familiarization**

After completing all MVC testing, the subject was given one hour to learn the climbing route used in this study. During this time the same expert climber who set the route gave verbal and visual demonstrations on how to climb the route most efficiently. The subjects were allowed and encouraged to climb the route as many times as they wanted in order to get as familiar with it as possible. Each subject used exactly the same hand sequencing to climb the route. Minor differences in foothold sequencing were permitted based on individual preference. Toward the end of the climbing familiarization hour, each subject climbed the route twice keeping pace with a metronome. The metronome was set to 71 beats per minute. Every third beat was

accented. The climber was instructed to make a hand move on every accented beat. When keeping with the metronome, the climbers made about 24 moves per minute.

### **Climbing route**

The climbing route used for this study was set on an indoor climbing wall. The angle of the wall was 40° overhanging (from vertical). A highly experienced professional rock climber and route-setter set the route by bolting plastic hand and footholds on the modular climbing wall. The difficulty of the climbing route was 5.11b on the YDS. Many subjective grading systems have been developed to qualify the difficulty of individual rock climbs (8,15,20). The most commonly used grading system in North America is the YDS. The technical climbing component of the YDS extends from 5.0 to 5.15. Rock climbs graded 5.10 or harder are further subdivided with the addition of letters a-d. Every effort was made to maintain homogeneity of difficulty in each section and move on the route. Each hold was the same color plastic and each hold was marked with white tape. The route consisted of a total of twenty-four moves (hand holds) from start to finish. The route started at six o'clock on the climbing wall and traveled in a clockwise circular manner up and around the perimeter of the climbing wall. The route finished on the same holds from which the route started. This circular design allowed for continuous climbing until the climber was no longer able to hang on. The low height of the climbing wall and the large (10" thick) mats covering the floor did not warrant the use of ropes or harnesses. Figure 4 shows the climbing wall and route.

### **Pre-fatiguing exercises**

On the five visits following familiarization, each subject was randomly assigned each pre-fatiguing exercise treatment and control (no pre-fatiguing exercise) immediately before one maximal bout on the climbing route. Each pre-fatiguing exercise was designed to target one of the four muscle groups of interest. Each pre-fatiguing exercise was done bilaterally. The muscle groups of interest were the digit flexors (DF), shoulder adductors (SA), elbow flexors (EF), and lumbar flexors (LF). DF exercise was used because grip and finger strength and endurance is positively correlated with climbing ability (9,10,15,) and performance (16,20). SA and EF exercise was used because research shows that pulling isotonic (10) and isometric (10,16) pull up endurance and single arm pull-up strength (20) are also positively correlated with climbing performance or ability. The frontal plane SA was chosen because the available literature shows that pull-up endurance on the frontal plane is correlated with climbing ability and performance (10,16). Muscular performance characteristics of the LF muscles have not been correlated with climbing ability (9,10). However LF exercise was used in the present study because it seems reasonable to assume that the LF muscles are active during climbing and that they contribute to climbing locomotion and stability. The exercises were implemented using systems of pulleys and weights. A Velcro strap was used to anchor the pulling rope to the subject's elbow and wrist for the SA and EF exercises, respectively. The use of the Velcro strap allowed for better isolation of the targeted muscle groups. A wooden dowel was held lightly in the hands of the subject during EF exercise to maintain a pronated forearm position. A padded board was used to hold down the subject's upper arm and isolate the DFs. The resistance of all exercises was set at 25 % of MVC. To set the resistance, a researcher measured the

minimum force required to hold the weight still at the pulling end up the rope (where the subject would be pulling) with the dynamometer. Weights were added or removed until the target force was reached. During each exercise the subject was required to isometrically hold the weights at a predetermined joint angle, body position or task. The predetermined joint angle was 90° at the elbow and shoulder for the EF and SA exercises, respectively. The predetermined body position for the LF exercise was holding the top of the half sit-up position of the YMCA half sit-up test (11). The required task of the DF exercise was that the subject could maintain a grip without slipping on the handhold. A researcher continuously monitored the subjects' performance in maintaining the aforementioned requirements of the exercise. When the subject failed to meet the requirement of the exercise (joint angle, body position, or grip), the researcher would lift the weight momentarily to allow the subject to reestablish the position. Fatigue was reached when the subject required adjustments more frequently than every five seconds. At the point of fatigue the exercise was terminated and the subject then hurried over to the climbing route. Recall of maximal Rating of Perceived exertion (RPE) using the Borg 15-grade scale (3) was taken following each pre-fatiguing exercise. Figure 5 shows each pre-fatiguing apparatus.

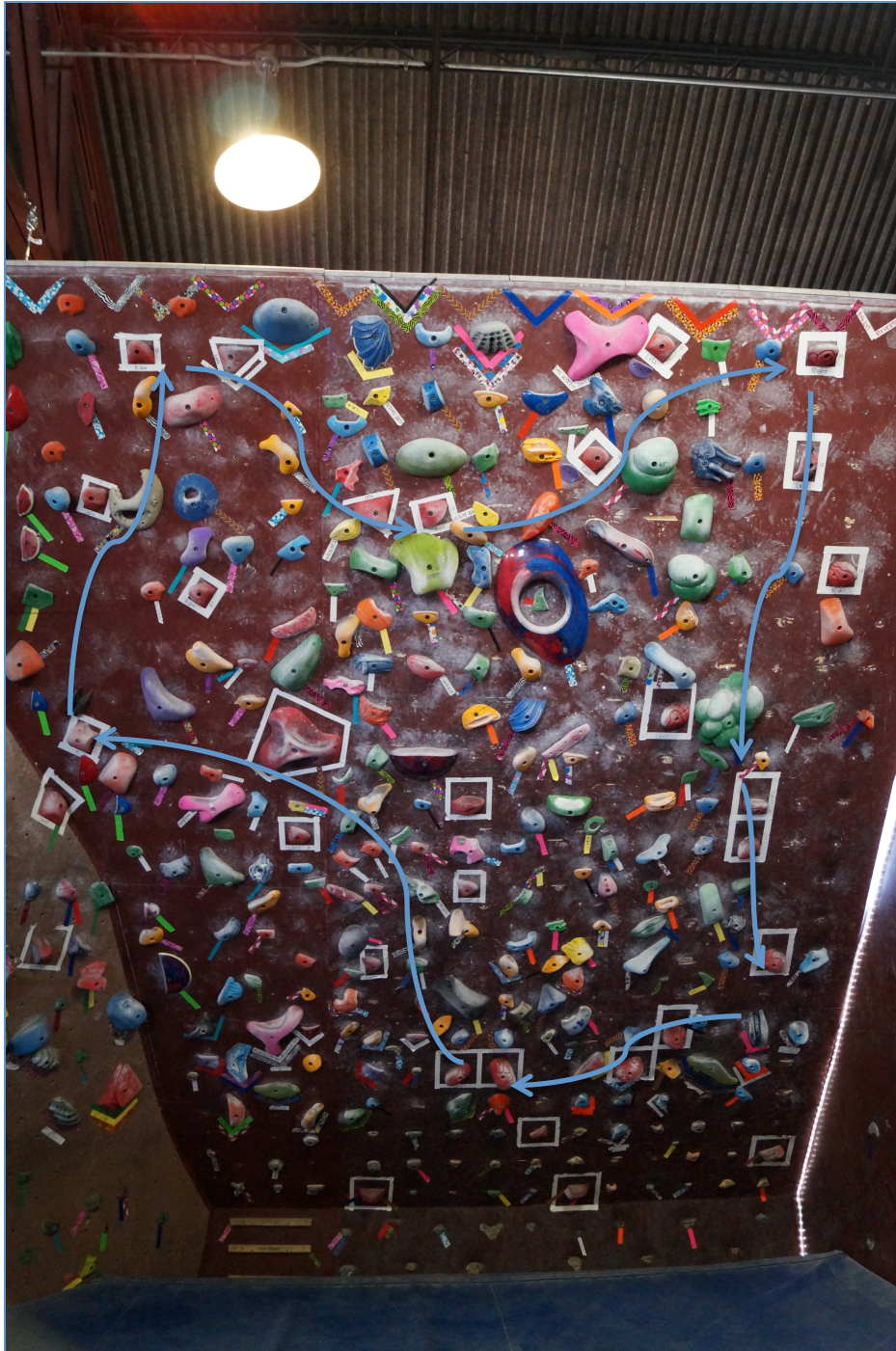


Figure 4. This figure shows the rock-climbing route used for the study. The hand and footholds are red and marked inside boxes of white tape arrows show the general path of the route and its continuous nature.





**Figure 5. This figure shows the weighted rope and pulley systems for each pre-fatiguing exercise. Clockwise from top left: digit flexion apparatus, shoulder adduction apparatus, elbow flexion apparatus, and lumbar flexion apparatus.**

Surface electromyography (EMG) was recorded on the subject's dominant side continuously from start to finish of each pre-fatiguing exercise at 3000 Hz using the Noraxon TeleMyo 2400T G2 (Noraxon, Scottsdale Arizona). Due to technical difficulties,

EMG data was lost for 2 subjects during DF exercise and for one subject during SA exercised. Electrodes were placed over the flexor digitorum superficialis (FDS) for pre-fatiguing exercise of the DF. Electrode placement was done according to the technique of Blackwell and colleagues (2). Using Noraxon's guidelines for lead placement (13) electrodes were placed over the latissimus dorsi (LD), pectoralis major (PM), and infraspinatus (IS) for pre-fatiguing exercise of the SA muscle group. Also using Noraxon's guidelines (13) electrodes were placed over the brachioradialis (BR) for the pre-fatiguing exercise of the EF muscle group. For the pre-fatiguing exercise of the LF muscle group electrodes were placed over the rectus abdominis (RA) 1 cm above the umbilicus and 2 cm from the midline. (17).

### **Climbing**

Immediately after termination of pre-fatiguing exercise the subject quickly walked or jogged to the climbing wall (50 feet away) and began climbing as quickly as possible. The subject was allowed to apply chalk (magnesium carbonate) to his hands just before commencing climbing but not after the start of the climb. The subject climbed for as long as possible continuously until he could not complete another move. No resting was allowed during the climb. The number of moves completed was recorded. For every handhold reached one point value was awarded. Partial points (0.5 points) were given if the subject unsuccessfully attempted to move to the next handhold. Unsuccessful attempts included letting go of a hold and moving toward the next hold or touching the next hold but not having control of it. For each trial, subjects climbed with the metronome amplified on the climbing gym sound system speaker.

The metronome was set to 71 beats per minute with the every third beat accented. The subjects were told to make hand moves on the accented beat (climbing rate = 24 moves per min) and the climbers kept pace with the metronome to the best of their ability. The researchers loosely enforced the climbing pace. The primary purpose of the metronome was to keep the subjects from resting.

Time was measured from the start of the pre-fatiguing exercise to the end of the climbing bout. Time at the end of pre-fatigue, start of route, and end of route was recorded. For each control trial, subjects briskly walked or jogged from where the pre-fatiguing exercise would have taken place (fifty feet from the climbing wall) and started climbing as quickly as possible. Time was measured from the start of the walking to the end of climbing for the control trial (data not presented here).

Maximal RPE recall was recorded after each climbing trial.

### **EMG Data processing**

EMG data was processed using Noraxon's frequency fatigue application. For each muscle measured, 12 one-second time points were selected evenly from start to end of the raw EMG data. Median frequency of each one-second time-point was plotted and fitted with a regression line. Slope of the line, start and end frequency, and percent decrease in frequency was calculated by Noraxon's frequency fatigue analysis.

### **Statistical Analysis**

Repeated measures ANOVA was used to test for significant differences in the means of pre-fatiguing times, RPE, transit times between pre-fatiguing exercise and climbing, climbing rate and moves completed during each trial. Tukey's Multiple Comparison Test was used when significant differences were found. Alpha level of  $p < 0.05$



0.05 was used for statistical significance. Prism GraphPad 5.04 (San Diego, CA) was used for statistical analyses.

## RESULTS

No significant differences were found among fatiguing exercise times, transit times, or climbing rate. These data are presented in Tables 3, 4, and 5 respectively. See Table 6 for RPE data. Table 7 shows the negative EMG median frequency slope and percent change in median frequency from start to end of the pre-fatiguing exercise for each muscle measured. Absolute number of moves completed for C, DF, EF, LF and SA trials were  $56.16 \pm 12.99$ ,  $28.36 \pm 12.61$ ,  $43.68 \pm 16.73$ ,  $49.59 \pm 13.61$ , and  $50.95 \pm 14.43$ , respectively. Climbing moves are expressed as a percentage of moves completed during the control climb for statistical analysis. Compared to the control climb significantly fewer moves were completed after DF pre-fatigue (Mean  $\pm$  SD = 50%  $\pm$  18% of control) and EF pre-fatigue (78%  $\pm$  22% of control). Fewer moves were completed following LF pre-fatigue (89%  $\pm$  17% of control) and SA pre-fatigue (92%  $\pm$  19% of control), but these were not significantly different. Significant differences were also found between the number of moves completed after DF pre-fatigue and all other conditions. Figure 6 shows these data graphically.

**Table 3. Fatigue time in seconds (sec.) for the digit flexors (DF), shoulder adductors (SA), elbow flexors (EF), and lumbar flexors (LF). No significant differences in fatigue times were observed ( $p > 0.05$ ) Standard deviation (SD).**

	DF (sec.)	SA (sec.)	EF (sec.)	LF (sec.)
Mean (SD)	386 (159)	317 (140)	259.5 (195)	349 (136)
Range	170-753	143-698	175-342	164-607

**Table 4. Transit times in seconds (sec.) from the end of pre-fatiguing exercise to the start of rock climbing for digit flexion (DF), shoulder adduction (SA), elbow flexion (EF), and lumbar flexion (LF) trials. No significant differences were found among transit times ( $p > 0.05$ ). Standard deviation (SD).**

	DF (sec.)	SA (sec.)	EF (sec.)	LF (sec.)
Mean (SD)	18.73 (3.0)	20.36 (3.1)	21.78 (6.0)	23.65 (4.4)
Range	13-23	15-26	14-33	19-33

**Table 5. Climbing rate in moves per minute (mv/min) for control (C), digit flexor, shoulder adductor, elbow flexor and lumbar flexor trials. Standard deviation (SD). No significant differences were found ( $p > 0.05$ ).**

	C (mv/min.)	DF (mv/min.)	SA (mv/min.)	EF (mv/min.)	LF (mv/min.)
Mean (SD)	27 (3)	27 (4)	27 (5)	26.5(4.5)	25.5 (2.5)
Range	21.5-32	19-32	18.5-24.5	20.5-35	20.5-28.5

**Table 6. Mean values of maximum RPE for Control (C), Digit flexor (DF), shoulder adductor (SA), elbow flexor (EF) and lumbar flexor (LF) trials for both the pre-fatiguing exercise (ex) and climbing (cl). No significant differences were found ( $p > 0.05$ ).**

	C <sub>cl</sub>	DF <sub>ex</sub>	DF <sub>cl</sub>	SA <sub>ex</sub>	SA <sub>cl</sub>	EF <sub>ex</sub>	EF <sub>cl</sub>	LF <sub>ex</sub>	LF <sub>cl</sub>
<b>Mean RPE (maximal)</b>	18	20	19	20	19	20	19	19	18

**Table 7. Slope and Mean and % decrease in median frequency from start to finish of exercise. + = measured during digit flexion. # = measured during shoulder adduction. ^ = measured during elbow flexion. \$ = measured during lumbar flexion.**

	Slope (mean $\pm$ SD)	% Change in median frequency (mean $\pm$ SD)
Flexor digitorum superficialis +	-1.83 $\pm$ .69	-22.99 $\pm$ 11.53
Latissimus dorsi #	-1.05 $\pm$ 1.00	-10.40 $\pm$ 15.25
Infraspinatus #	-3.38 $\pm$ 2.36	-33.48 $\pm$ 16.76
Pectoralis major #	-0.37 $\pm$ 0.55	-6.48 $\pm$ 10.60
Brachioradialis ^	-1.56 $\pm$ 0.95	-16.48 $\pm$ 15.21
Rectus abdominis \$	-3.01 $\pm$ 2.12	-31.88 $\pm$ 17.54

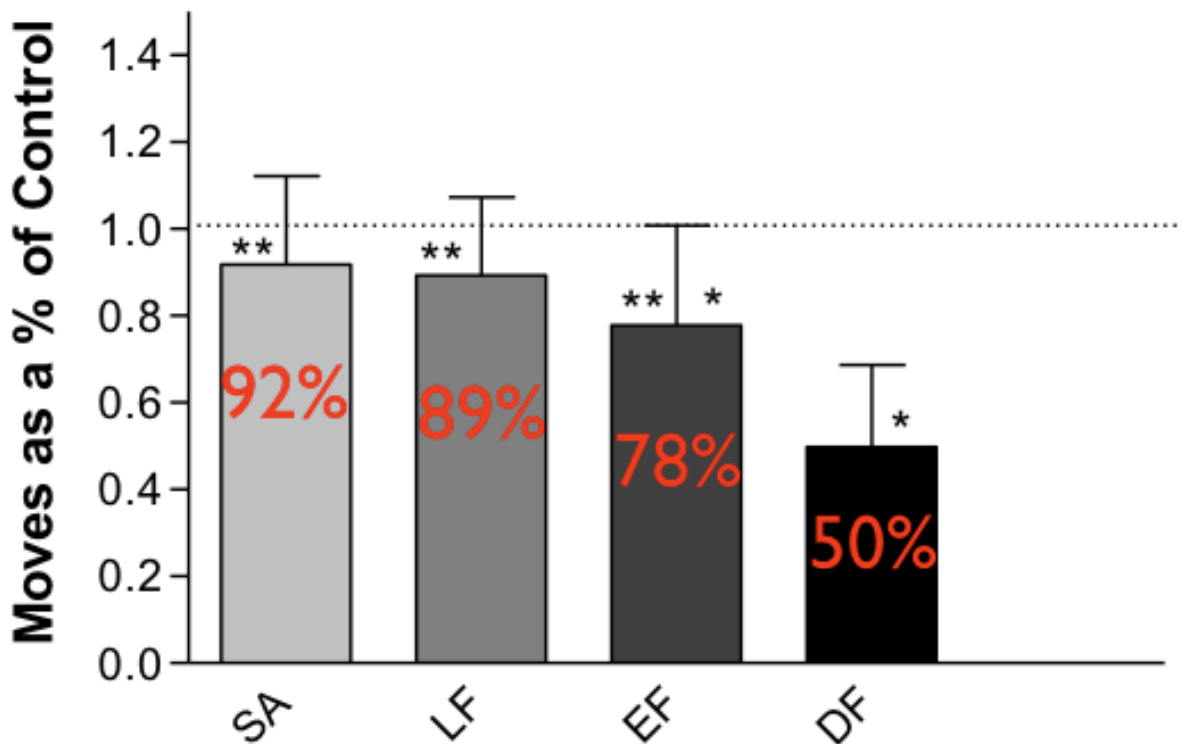


Figure 6. Climbing hand moves completed after each pre-fatiguing condition. Control is equal to 1.0 on the y-axis (dotted line). Shoulder adductors (SA), lumbar flexors (LF), elbow flexors (EF) and digit flexors (DF). \* Indicates significant difference from control. \*\* Indicates significant difference from DF.  $p < 0.05$ .

## DISCUSSION

Most studies examining muscle strength, power, endurance or fatigue in rock climbing have done so indirectly by correlating muscle performance characteristics with climbing performance (16,23) ability (9,19,15,20), or by using a model of rock climbing (1,6,19). Some studies have directly measured reduced strength and endurance of the forearm muscles using grip dynamometry after indoor climbing (21,24). To our knowledge, the present study is the first to directly and individually look at the muscles of the forearm as well as other muscle groups with respect to their

impact on climbing performance. We also believe these results may be especially applicable to the sport because actual climbing performance on a designated route is the dependent variable in this study.

The most significant finding of this study, consistent with our hypothesis, is that climbing performance is reduced the most after pre-fatigue of the DF followed by the EF (Figure 6). Climbing performance following pre-fatigue of LF and SA was reduced compared to control but these differences are not significant.

The lack of a significant difference following LF pre-fatigue is not surprising given that, to date, no study has shown that strength or endurance of the abdominal muscles is related to climbing ability (9,10). It is possible that a different climbing route that is more overhanging or with smaller foot holds may have required more abdominal muscle activation. It is also possible that the apparatus used for pre-fatiguing LF, which exerted force primarily through the sagittal plane, lacked climbing specificity.

The lack of a significant reduction in climbing performance following SA fatigue is puzzling given the anecdotal (23) and correlative (10,16,20) support for shoulder girdle muscle function in climbing. However, the studies that correlated shoulder girdle function to climbing performance used some version of a pull-up or pulling action to measure strength and endurance of the shoulder and arm (10,16,20). These exercises are coupled with both elbow flexion as well as gripping, and therefore do not isolate the shoulder girdle muscles. The present results suggest that the elbow flexing and/or gripping component, not the shoulder adduction component of the pull-up action, may be the limiting factor. Perhaps the higher strength and endurance in the pulling

exhibited by higher performing climbers (10,16,20) should be attributed to strength and endurance of the EF or DF that were also involved in those exercises.

It has been suggested that as the difficulty of the rock climb increases more work is distributed from the lower body to the arm and shoulders (8). The difficulty of the climbing route used in this study (5.11b) was one full grade below the average subject's reported ability (5.12b). Perhaps the low relative intensity of the route used in this study did not require as much use of the shoulder adductors.

Frontal plane shoulder adduction was used because pulling endurance of the shoulders adductors operation on the frontal plane have been shown to be positively correlated with climbing performance (10,16). It is possible that pre-fatiguing exercise of with isometric shoulder extension may have had a greater impact on climbing performance. By moving the forces to the sagittal plane with shoulder extension, many of the same muscle would be challenged, but perhaps in a more climbing specific way.

A final observation possibly related to the lack of reduction in climbing performance with fatigued SA is speculative regarding post occlusive reactive hyperemia (PORH). A Velcro strap was used to anchor rope to the subject's elbow during SA pre-fatiguing exercise. The purpose of this arrangement was to isolate the SA muscle group and keep the EF and DF muscle groups from contracting. Despite keeping the Velcro strap loose around the subject's arm, the nature of this arrangement likely resulted in some occluded blood flow to the forearm. Research shows that following occlusion, robust vasodilation results in excessive blood flow distal to the occluded site for several minutes (6). This phenomenon is called PORH. Climbers have been shown to have greater PORH response and vascular conductance in the forearm compared to

sedentary non-climbers (6). It seems possible that after removal of the arm straps on the SA pre-fatiguing apparatus that the subjects could have experienced PORH to the forearm. The preemptive hyperemia to the forearm before the start of the climb may have delayed fatigue at the level of the forearm during climbing and offset the negative impact of SA fatigue to climbing performance.

No significant differences were observed in times to fatigue among the four muscle groups studied (Table 3). The EF muscle group, however, appeared to show a shorter time to fatigue compared to the other muscles groups. Because the present results suggest that the EF muscle group is very important for climbing and that the EF appear to have a shorter duration to fatigue, training strategies aimed at improving the fatigue resistance of the EF muscle group (especially the brachioradialis) may be beneficial for climbing performance.

All muscles observed with EMG showed decreases in median frequency from beginning to end of each pre-fatiguing exercise (Table 7). The percent difference from beginning to end frequency in the FDS muscle in the present study was very similar to results from Petrofsky and coworkers (-23% v.s -24%) (18). However, the slope of median frequency over time in the present study was greater than reported previously (-1.8 vs. -0.84) (19).

The nature of the climbing wall and the repeated climbing of the same route could pose potential limitations. The looping nature of the route used for this study makes for a combination of positive vertical displacement climbing (climbing up), horizontal displacement climbing (traversing) and negative vertical displacement (downclimbing). Positive vertical displacement may increase the physiological demand

of climbing compared to traverse climbing (7) or down climbing. Therefore, while we tried to make the technical difficulty of the climb used in this study uniform, the physiological demands of the route may have varied with climbing direction. The use of a climbing ergometer (Treadwall©) would be a suitable approach to control for this variable. Climbers have been shown to adapt to a specific rock climb after repeated practice over several weeks (5). In an effort to control for the learned effect on this route, pretesting familiarization and a randomized design was used.

The main findings of this study show that after pre-fatiguing of the DF, climbing performance is significantly reduced to the greatest degree followed by the EF muscle group. These results suggest that among the muscle groups studied, DF and EF muscle groups show primary and secondary performance, respectively, followed by LF and SA that both showed a non-significant difference compared to the control climb.

## **PRACTICAL APPLICATIONS**

Strength and conditioning strategies that improve fatigue resistance of certain important muscle groups and improve climbing techniques so that there is a reduced reliance on DF and EF muscle groups may be useful strategies for those working with male climbers to improve climbing performance on 40° overhanging terrain.

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## CHAPTER 4

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### Summary

The review manuscript highlighted the need for more literature aimed at elucidating the physiological demands of rock climbing as well as variables and training techniques that improve rock climbing performance. This review points out that training is commonplace among climbers and more literature is needed on the topic so that more research-informed and efficient training strategies can be implemented

The research manuscript called “The Relative Importance of Four Muscle Groups for Indoor Rock Climbing Performance” for the first time provided evidence to support

the commonly held hypothesis that the forearm musculature is the most important muscle group for rock climbing, specifically for routes overhanging at 40° from vertical in men. This study also provided novel information about the importance of other muscle groups of the upper body to rock climbing performance.

### Conclusions

The significant findings were DF and EF muscle are especially important for rock climbing performance. LF and SA showed much less importance. It is important to note that these data regarding the LF and SA muscle groups should be interpreted with caution. Other rock climbs of varied steepness, hold availability or of different absolute and relative difficulty, may prove to require more work distribution to the LF and/or SA muscles.

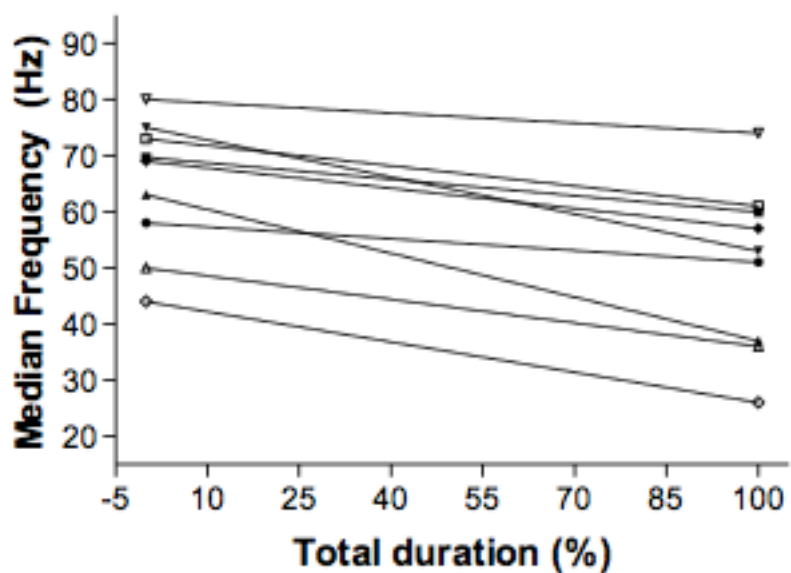
### Recommendations

Training strategies that reduce the fatigability of the DF and EF and climbing strategies that reduce the reliance on those muscle groups should be implemented to improve rock climbing performance. Future research could use a Treadwall© for to allow for continuous climbing without downclimbing or traversing movement. It is suggested that future research also look at the importance of these and other muscle groups at various angles of terrain, in women, and at different absolute and relative climbing difficulty.

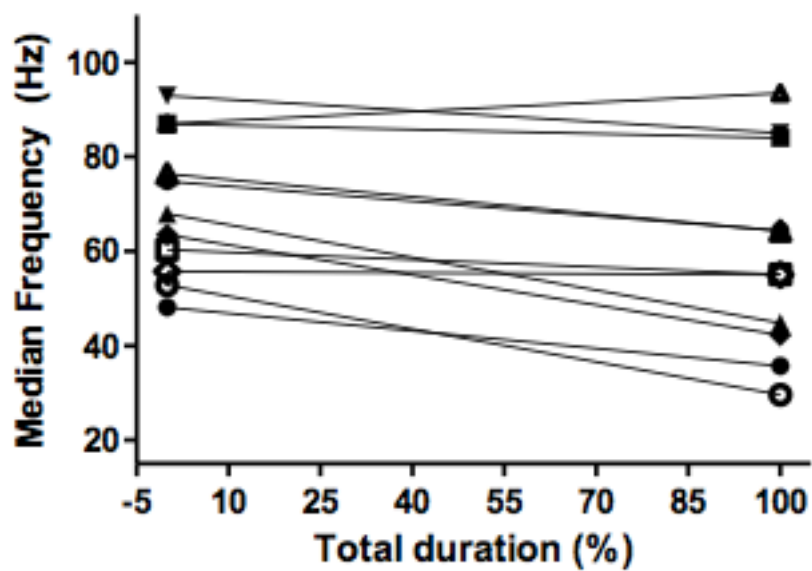
## **Appendices**

- A. Supplemental Figures
- B. Combined Consent/HIPAA Form
- C. Flyer
- D. Data collection sheets
- E. Health History Questionnaire

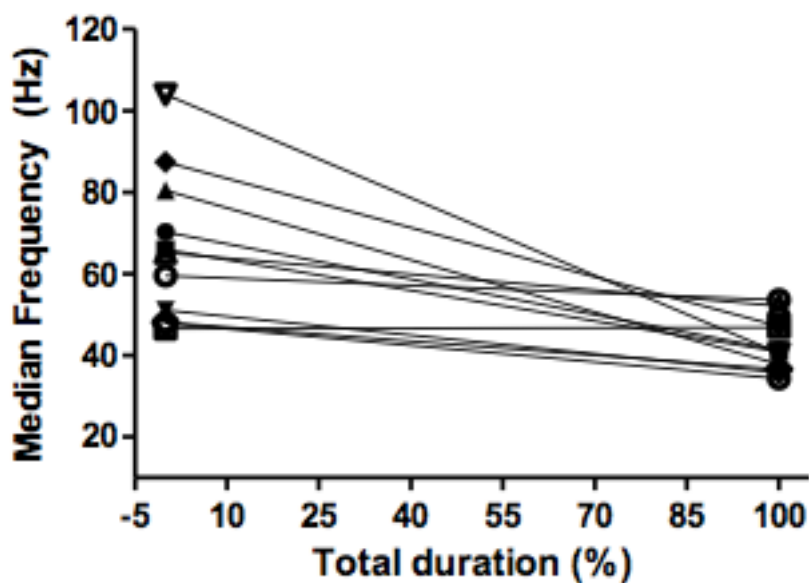
## APPENDIX A.



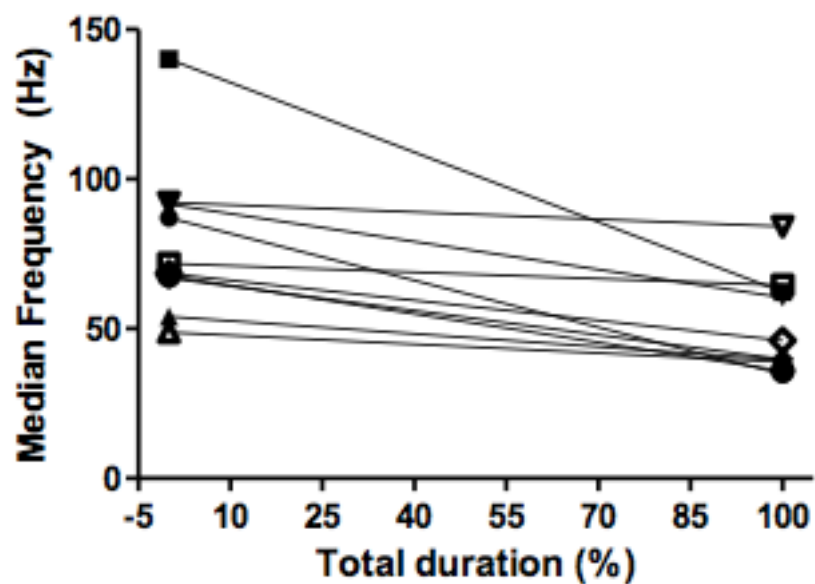
Supplemental Figure 1. Median frequency of the flexor digitorum superficialis during digit flexion pre-fatigue exercise at start and finish for nine subjects.



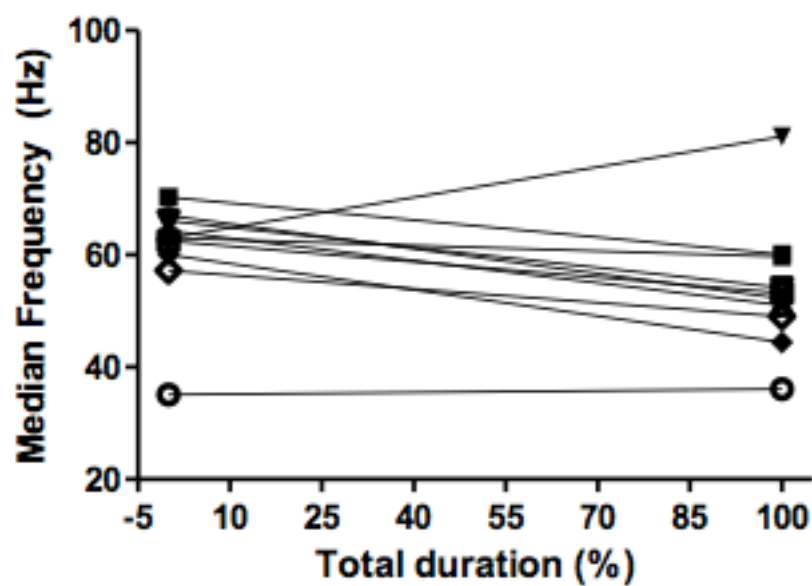
Supplemental Figure 2. Median frequency of the brachioradialis during elbow flexion pre-fatigue exercise at start and finish for each subject.



Supplemental Figure 3. Median frequency of rectus abdominis during lumbar flexion pre-fatigue exercise at start and finish for each subject.



Supplemental Figure 4. Median frequency of the infraspinatus during shoulder adduction pre-fatigue exercise at start and finish for each subject.



Supplemental Figure 5. Median frequency of the latissimus dorsi during shoulder adduction pre-fatigue exercise at start and finish for 10 subjects.

## **APPENDIX B.**

### **The University of New Mexico Health Sciences Center Consent to Participate in Research**

#### **Relative importance of four muscle groups for indoor rock climbing performance.**

##### **Purpose and General Information**

**You are being asked to participate in a research study that is being done by Christine Mermier, Ph.D., who is the Principal Investigator, and her associates. This research is being done to evaluate the relative importance of four muscle groups in rock climbing performance. You are being asked to participate because you are a healthy, experienced rock climber (who regularly climbs at least Yosemite Decimal System climbing rating of 5.12) between the ages of 18 and 44. Approximately 11 people will take part in this study at Kirtland Air Force Base ODR climbing Gym in Albuquerque, NM.**

**This form will explain the study to you, including the possible risks as well as the possible benefits of participating. This is so you can make an**



**informed choice about whether or not to participate in this study. Please read this Consent Form carefully. Ask the investigators or study staff to explain any words or information that you do not clearly understand.**

**What will happen if I participate?**

**If you agree to be in this study, you will be asked to read and sign this Consent Form. After you sign the Consent Form, the following things will happen: Participation in this study will take a total of 6-7 hours over a period of four to six weeks.**

**What are the possible risks or discomforts of being in this study?**

**Every effort will be made to protect the information you give us. However, there is a small risk of loss of privacy and/or confidentiality. You may experience some discomfort in your muscles during the pre-fatiguing exercises and/or during the climbing bouts. Since you are an experienced rock climber, it is expected that the muscular discomfort you may feel during the study will not be different than what you regularly experience during climbing. You may be inconvenienced by the number of visits required (6 visits), and the time commitment needed, as well as refraining from exercise the day before each session. There is a very small risk that you may be injured during the performance of the exercise or climbing bouts, but this risk will be reduced by the use of safety equipment, spotting techniques, and specific instructions to reduce risks.**

**How will my information be kept confidential?**

**Your name and other identifying information will be maintained in locked files, available only to authorized members of the research team, for the duration of the study. Any personal identifying information and any record linking that information to study ID numbers will be destroyed when data analysis is complete. Information resulting from this study will be used for research purposes and may be published; however, you will not be identified by name in any publications.**

**Information from your participation in this study may be reviewed by federal and state regulatory agencies, and by the UNM Human Research Review Committee (HRRC) which provides regulatory and ethical oversight of human research. There may be times when we are required by law to share your information. However, your name will not be used in any published reports about this study.**

**What are the benefits to being in this study?**

**There may or may not be direct benefit to you from being in this study. However, your participation may help us find out which muscle groups are**

most important for rock climbing. This may help climbing coaches and climbing enthusiasts develop training programs specifically aimed at improving the fatigability or climbing-specific function of the muscle groups deemed most important.

**What other choices do I have if I don't participate?**

Taking part in this study is voluntary so you can choose not to participate.

**Will I be paid for taking part in this study?**

You will not be compensated for your participation

**What will happen if I am injured or become sick because I took part in this study?**

If you are injured or become sick as a result of this study, UNMHSC will provide you with emergency treatment, at your cost.

No commitment is made by the University of New Mexico Health Sciences Center (UNMHSC) to provide free medical care or money for injuries to participants in this study.

In the event that you have an injury or illness that is caused by your participation in this study, reimbursement for all related costs of care will be sought from your insurer, managed care plan, or other benefits program. If you do not have insurance, you may be responsible for these costs. You will also be responsible for any associated co-payments or deductibles required by your insurance.

It is important for you to tell the investigator immediately if you have been injured or become sick because of taking part in this study. If you have any questions about these issues, or believe that you have been treated carelessly in the study, please contact the Human Research Review Committee (HRRC) at the (505) 272-1129 for more information.

**How will I know if you learn something new that may change my mind about participating?**

You will be informed of any significant new findings that become available during the course of the study, such as changes in the risks or benefits resulting from participating in the research or new alternatives to participation that might change your mind about participating.

**Can I stop being in the study once I begin?**

Yes. You can withdraw from this study at any time without any penalty

The investigators have the right to end your participation in this study if they determine that you no longer qualify to take part, if you do not follow study procedures, or if it is in your best interest or the study's best interest to stop your participation. If you withdraw, we will give you the results of any testing you completed if you request. You have the right to request that we destroy your data if you withdraw or are withdrawn from the study.

### **HIPAA Authorization for Use of Your Protected Health Information (HIPAA)**

As part of this study, we will be collecting health information about you. This information will not be shared with anyone other than the study team. This information is "protected" because it is identifiable or "linked" to you.

### **Protected Health Information (PHI)**

By signing this Consent Document, you are allowing the investigators and other authorized personnel to use your protected health information for the purposes of this study. This information may include: age, height, weight, resting blood pressure, percent body fat, strength and fatigue information, and information derived from the health questionnaire and the climbing questionnaire. Should you not qualify for the study, all information collected will be destroyed.

In addition to researchers and staff at UNMHSC and other groups listed in this form, there is a chance that your health information may be shared (re-disclosed) outside of the research study and no longer be protected by federal privacy laws. Examples of this include disclosures for law enforcement, judicial proceeding, health oversight activities and public health measures.

### **Right to Withdraw Your Authorization**

Your authorization for the use of your health information for this study shall not expire unless you cancel this authorization. Your health information will be used as long as it is needed for this study. However, you may withdraw your authorization at any time provided you notify the UNM investigators in writing.

Please be aware that the research team will not be required to destroy or retrieve any of your health information that has already been used or shared before your withdrawal is received.

### **Refusal to Sign**

If you choose not to sign this consent form and authorization for the use of your PHI, you will not be allowed to take part in the research study.

**What if I have questions or complaints about this study?**

If you have any questions, concerns or complaints at any time about the research study, Michael Deyhle, will be glad to answer them at 505-321-7388. If you would like to speak with someone other than the research team, you may call the Human Research Review Committee (HRRC) at (505) 272-1129. The HRRC is a group of people from UNMHSC and the community who provide independent oversight of safety and ethical issues related to research involving human participants.

**What are my rights as a research participant?**

If you have questions regarding your rights as a research participant, you may call the Human Research Protections Office (HRPO) at (505) 272-1129 or visit the HRPO website at <http://hsc.unm.edu/som/research/hrrc/>.

**Consent and Authorization**

You are making a decision whether to participate in this study. Your signature below indicates that you read the information provided (or the information was read to you). By signing this Consent Form, you are not waiving any of your legal rights as a research participant.

I have had an opportunity to ask questions and all questions have been answered to my satisfaction. By signing this Consent Form, I agree to participate in this study and give permission for my health information to be used or disclosed as described in this Consent Form. A copy of this Consent Form will be provided to me.

\_\_\_\_\_  
Name of Adult Participant (print)  
Participant Date

\_\_\_\_\_  
Signature of Adult

I have explained the research to the participant and answered all of his/her questions. I believe that he/she understands the information in this consent form and freely consents to participate.

\_\_\_\_\_  
Name of Research Team Member  
Member Date

\_\_\_\_\_  
Signature of Research Team

## APPENDIX C.

### **Climbers needed for UNM research study at Kirtland AFB Outdoor Recreation Climbing Gym HRRC # 13-508**

**What is the study about?** This study may help us better understand what muscle groups are most important for rock climbing.

**Who can volunteer?** Climbers 18-44 yrs with at least 1 year climbing experience who can redpoint 5.12 rock climbs. Volunteers cannot be diagnosed with neuromuscular, cardiovascular disease or current muscular/skeletal injury.

**Is compensation provided?** No compensation will be provided.

**Who can I contact for more information?**  
Michael Deyhle, 505-321-7388, [mdeyhle@unm.edu](mailto:mdeyhle@unm.edu) or  
Christine Mermier, 505-277-2664, [cmermier@unm.edu](mailto:cmermier@unm.edu)



**APPENDIX D.**

Data collection sheet, Familiarization

Study #13-508 Data Collection sheet Pre-Fatigue Climbing study

Subject ID # \_\_\_\_\_ Age (years) \_\_\_\_\_

Sex \_\_\_\_\_ Weight (lbs) \_\_\_\_\_

Height (in) \_\_\_\_\_ Hand Dominance \_\_\_\_\_

- Number of years climbing \_\_\_\_\_
- Number of years climbing indoor gym climbing \_\_\_\_\_

- Number of days per month you climb (year average) \_\_\_\_\_
- Hardest outdoor flash/onsight (route completed in first attempt) \_\_\_\_\_
- Hardest outdoor redpoint (route completed after 2 or more attempts) \_\_\_\_\_
- Hardest indoor onsight \_\_\_\_\_
- Hardest indoor redpoint \_\_\_\_\_
- Current indoor onsight ability \_\_\_\_\_
- Current indoor redpoint ability \_\_\_\_\_

Skinfold (3 sight)

Male

Chest			Abdomen			Thigh		

Sum (mm) \_\_\_\_\_

Female

Triceps			Suprailiac			Thigh		

Sum (mm) \_\_\_\_\_

Hand Grip Dynamometry

Right Hand (lbs/kg)			Left Hand (lbs/kg)		

Maximum (R) \_\_\_\_\_

Maximum (L) \_\_\_\_\_

Shoulder Adduction Dynamometry

Right (lbs/kg)			Left (lbs/kg)		
Maximum (R) _____			Maximum (L) _____		

### Elbow Flexion Dynamometry

Right (lbs/kg)			Left (lbs/kg)		
Maximum (R) _____			Maximum (L) _____		

### Trunk Flexion Dynamometry

lbs/kg		
Maximum _____		

### Data collection sheet, trials

Study # 13-508

Subject ID # \_\_\_\_\_

Test day # \_\_\_\_\_

Muscle group fatigued (randomized) \_\_\_\_\_

Resistance on pre-fatiguing exercise (pounds) \_\_\_\_\_

Pre-fatiguing exercise duration (sec) \_\_\_\_\_

RPE at end of Pre-fatiguing exercise \_\_\_\_\_

Number of moves completed (hand holds) \_\_\_\_\_





Heart attack/Myocardial Infarction problems	_____	Heart surgery	_____	Valve	
Chest pain or pressure	_____	Swollen ankles	_____	Dizziness	_____
Arrhythmias/Palpitations	_____	Heart murmur	_____	Shortness of	
breath	_____			Congestive heart failure	_____

Have you ever had any of the following? Please check all that apply.

Cancer (specify type)	_____	High blood pressure	_____	Thyroid problems	_____
Rheumatic fever	_____	Obesity	_____	Total cholesterol >200	
Kidney/liver disease	_____				
mg/dl	_____	Asthma	_____	HDL cholesterol <35	
Diabetes (specify type)	_____	Stroke	_____	LDL cholesterol >135	
mg/dl	_____			Triglycerides >150	
Emphysema	_____				
mg/dl	_____				
mg/dl	_____				

Do immediate blood relatives (biological parents & siblings **only**) have any of the conditions listed above? If yes, list the problem, and family member age at diagnosis.

\_\_\_\_\_

Do you currently have any other medical condition not listed?

Details \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Indicate level of your overall health. Excellent \_\_\_\_\_ Good \_\_\_\_\_ Fair \_\_\_\_\_ Poor \_\_\_\_\_



Are you taking any medications, vitamins or dietary supplements now?      Y      N

If yes, what are they? Please list dosage if known.

[illegible]

Do you have allergies? If yes, what are they?

---

Are you allergic to latex?      Y      N

Have you ever experienced any adverse effects during or after using caffeine or other supplements? Y N If yes, elaborate.

---



## Tobacco & Caffeine Consumption

Do you currently use tobacco?      Y   N   If yes: type \_\_\_\_\_

How long?\_\_\_\_\_ Quantity\_\_\_\_\_/day Years since quitting\_\_\_\_\_

How often do you drink the following?

Caffeinated coffee or tea oz/wk

Decaffeinated coffee or tea oz/wk

Caffeinated soft drink \_\_\_\_\_ oz/wk

Other substances containing caffeine- please describe

