2019

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STARS Citation
Marsala, Michael, "Ultrasound Measured Flexor Muscle Thickness in the Forearms of Rock Climbers" (2019). *Electronic Theses and Dissertations*. 6529.
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ULTRASOUND MEASURED FLEXOR MUSCLE THICKNESS IN THE FOREARMS OF ROCK CLIMBERS

by

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B.S. University of Central Florida, 2017

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Sport and Exercise Science
in the School of Kinesiology and Physical Therapy
in the College of Health Professions and Sciences
at the University of Central Florida
Orlando, Florida

Summer Term
2019

Major Professor: Jeanette Garcia

ABSTRACT

PURPOSE: To examine differences in the forearms of rock climbers using ultrasound to measure the muscle thickness of the finger flexors. **METHODS:** A total of 33 participants were recruited, 22 climbers (22.23 years; 68% male) and 11 controls (21.8; 55% male). Climbers provided self-reported ratings of their climbing ability, skill level, and preferred mode of climbing (e.g. sport climbing vs. bouldering). Anthropometric measures, including body fat percentage, were measured in all participants. Ultrasound measurements were taken with the participant lying on their back on a padded table with their dominant hand supinated. Muscle thickness measurements were taken at the forearm where a peak of the forearm flexors was identified on the medial aspect of the forearm after a circumference measurement and small mark was made. The distance from the ulna and radius to the muscle-skin interface was measured, as well as echo intensity surrounding the median nerve using a third party program. **RESULTS:** Approximately 50% of climbers rated themselves as "intermediate", and the other 50% rated themselves as "advanced" climbers, while 77% of the 22 climbers classified themselves as primarily "sport climbers", and 23% classified themselves as "boulderers". Body fat percentages were significantly different at 19.14±6.99 and 30.02±7.6 for climbers and controls. Ulnar and radial muscle thickness values were significantly higher in climbers, 4.23±.39and 2.32±.39, respectively, and 3.61±.6 and 1.84±.31 in controls ($p<.001$). No differences in echo intensity were observed between climbers and non-climbers. **DISCUSSION:** The findings suggests that there are differences in flexor muscle thickness observed in earlier stages of rock climbing. Echo intensity of the flexor muscles were also measured, however significant variance in results warrants further investigation. Future studies should consider larger samples to better determine differences among muscle thickness and echo intensity across climbing abilities and mode of climbing, thus allowing for more specific training programs to be developed at each phase of training.

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CHAPTER ONE: INTRODUCTION

Rock climbing is a highly technical sport that requires a high degree of coordination, as well as full-body conditioning to perform such movements (Larew & Haibach-Beach, 2017; Phillips, Sassaman, & Smoliga, 2012). Although the entire body is utilized in climbing, the forearms are particularly emphasized in a unique manner in which the fingers become weight bearing joints. The forearms have often been implicated as the rate-limiting factor in performance measures (Baláš et al., 2014; Limonta et al., 2018; Quaine, Vigouroux, & Martin, 2003; Schoeffl, Klee, & Strecker, 2004), and are frequently the focus of studies to find ideal training protocols. (Levernier & Laffaye, 2017; López-Rivera & González-Badillo, 2012; Medernach, Kleinöder, & Lötzerich, 2015).

Forearm activity during rock climbing is defined by intermittent isometric contraction of the fingers moving from hold to hold (Esposito et al., 2009; Quaine et al., 2003; Phillip B. Watts, 2004) and a high rate of force development (RFD) (Fanchini, Violette, Impellizzeri, & Maffiuletti, 2013; Levernier & Laffaye, 2017; Phillip B. Watts, 2004) to support the climber's weight before the acceleration of gravity takes over. Due to the high intensity and technical demands of rock climbing, the sport favors higher strength-to-weight ratios in the fingers rather than absolute handgrip strength (Macleod et al., 2007; Philippe, Wegst, Müller, Raschner, & Burtscher, 2012; Quaine et al., 2003; Vigouroux & Quaine, 2006).

In rock climbing, the two very common techniques used to grasp a hold are called the crimp and the slope grip and the mechanics and musculature involved in them have been studied extensively (Schöffl et al., 2009; Schweizer, 2001; Vigouroux, Quaine, Labarre-Vila, & Moutet, 2006; Quaine & Vigouroux, 2004). Crimping is defined by a hyper-extension of the distal interphalangeal joint (DIP), and a strong flexion of the proximal interphalangeal joint (PIP), this is used to hang from holds than can be smaller than the fingertip. The slope grip relies on a flexion through the finger joints not exceeding 90 degrees, usually on smooth and rounded surfaces(Vigouroux, Goislard de Monsabert, & Berton, 2015) In rock climbers, forces measured at the fingertips in these grips have ranged from 412 N - 481 N (España-Romero & Watts, 2012; Vigouroux & Quaine, 2006).

The primary musculature used in these grips are the flexor digitorum superficialis (FDS), for flexion about the DIP and the flexor digitorum profundus (FDP) for flexion about the PIP, the flexor carpi radialis (FCR) is also used to flex the wrist into occasional sloping surfaces. These muscles can all be found in the anterior, or flexor, component of the forearm. It has been observed that an increase in ultrasound measured muscle thickness between the ulna (MT ulna) and radius (MT Radius) and the muscle skin interface of the forearms was correlated with an increase in grip strength (Abe et al., 2015; Abe, Nakatani, & Loenneke, 2018).

After simple technique is learned, the ability of the forearms can limit a climber. At the start of a training program, initial increases in strength are primarily attributed to neural adaptations, with later gains attributed to muscle hypertrophy (Moritani & deVries, 1979). The extent of muscular hypertrophy required for optimal performance is unknown beyond the neural adaptation (España-Romero & Watts, 2012; Vigouroux & Quaine, 2006) oxidative capacity (Fryer et al., 2015, 2016, 2017) and RFD (Fanchini et al., 2013; Levernier & Laffaye, 2017). Measuring the cross-sectional area (CSA) of muscles is best done via magnetic resonance imaging (MRI), however this is costly and time consuming. Abe, Nakatani and Loenneke (2018) found that measuring the thickness of the anterior portion of the forearms from the ulna and radius to the fat and skin layers was significantly correlated with MRI measured CSA, signifying an accurate and alternative method of measuring of the flexor muscles used in climbing.

The size of rock climber’s forearms has been measured in the past via circumference (Esposito et al., 2009; Limonta et al., 2018; Macleod et al., 2007) and volume (España-Romero & Watts, 2012; Fryer et al., 2017; P B Watts, Joubert, Lish, Mast, & Wilkins, 2003) with varying results. Circumference and volume measurements include more than just the flexor muscles in climbing, most notably the brachioradialis, an important muscle for climbing for elbow flexion while the hand is pronated (Boccia, Pizzigalli, Formicola, Ivaldi, & Rainoldi, 2015). The muscle thickness on top of the ulna is a more direct measurement of the size of the finger flexors and is not influenced by the considerable size of the brachioradialis. The present study aims to measure hypertrophic adaptations to climbing in the finger flexors to relatively early climbing careers. It is hypothesized that there will be notable differences in the thickness finger flexors when compared to controls in contrast to previous statements about neuromuscular adaptation over hypertrophy explaining the difference between climbers and controls. This could help coaches and athletes tailor their training for greater improvements in climbing ability at ability levels more commonly found in the climbing community.

CHAPTER TWO: LITERATURE REVIEW

Overview of Climbing

Competitive, indoor rock climbing, newly featured in the 2020 Olympics, is focused around three disciplines: sport climbing, bouldering and speed climbing. Sport climbing and bouldering are the most popular indoor sports today, as the vast majority of climbing gyms can offer these at very low risk. Sport climbing involves the use of a rope to prevent falling, as sport "routes" are high enough to cause serious injury or death. As the climber ascends the route, they clip their rope into "quickdraws", which protect the climber, should the climber fall (Giles, Rhodes, & Taunton, 2006). The route is finished when the rope is placed in the final quickdraws. In contrast, bouldering derives its name from climbing freestanding boulders outdoors. Indoor bouldering walls are rarely over 15 feet, and there is no protection from falls beyond a padded floor. Bouldering is a much higher intensity activity than sport climbing, as the distance travelled and time spent moving is much shorter in duration. Instead of routes in sport climbing, boulderers climb "problems" as opposed to routes in sport climbing (Schweizer, 2012). The third discipline, speed climbing, typically takes place indoors on an artificial climbing wall, and unlike sport climbing and bouldering, focuses on speed and explosive power, in a practiced motion. These climbing walls are very strictly regulated by the International Federation of Sport Climbing (IFSC) and every ascent is the same. There are strong differences between sport climbers and boulderers apparent in force output and endurance (Fryer et al., 2017). For example, sport climbs average ~2-7 minutes in duration (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995), bouldering <60 (White & Olsen, 2010) seconds, and competitive speed climbs <15 seconds ("Speed World Record Overview," 2019). Speed climbing is not included in this study due to the lack of similarity to sport and bouldering, popularity and a lacking of literature into the physiology of speed climbing.

Classifying Ability

The difference between each rating is often subjective, and can vary according to who set the route, whether they identified and rated an outdoor climb or created an indoor route. Therefore, no standardized classification system currently exists to differentiate between ratings. Climbers typically measure their abilities using rating scales, such as the YDS (Giles, Rhodes, & Taunton, 2006).

History and Issues in Classification

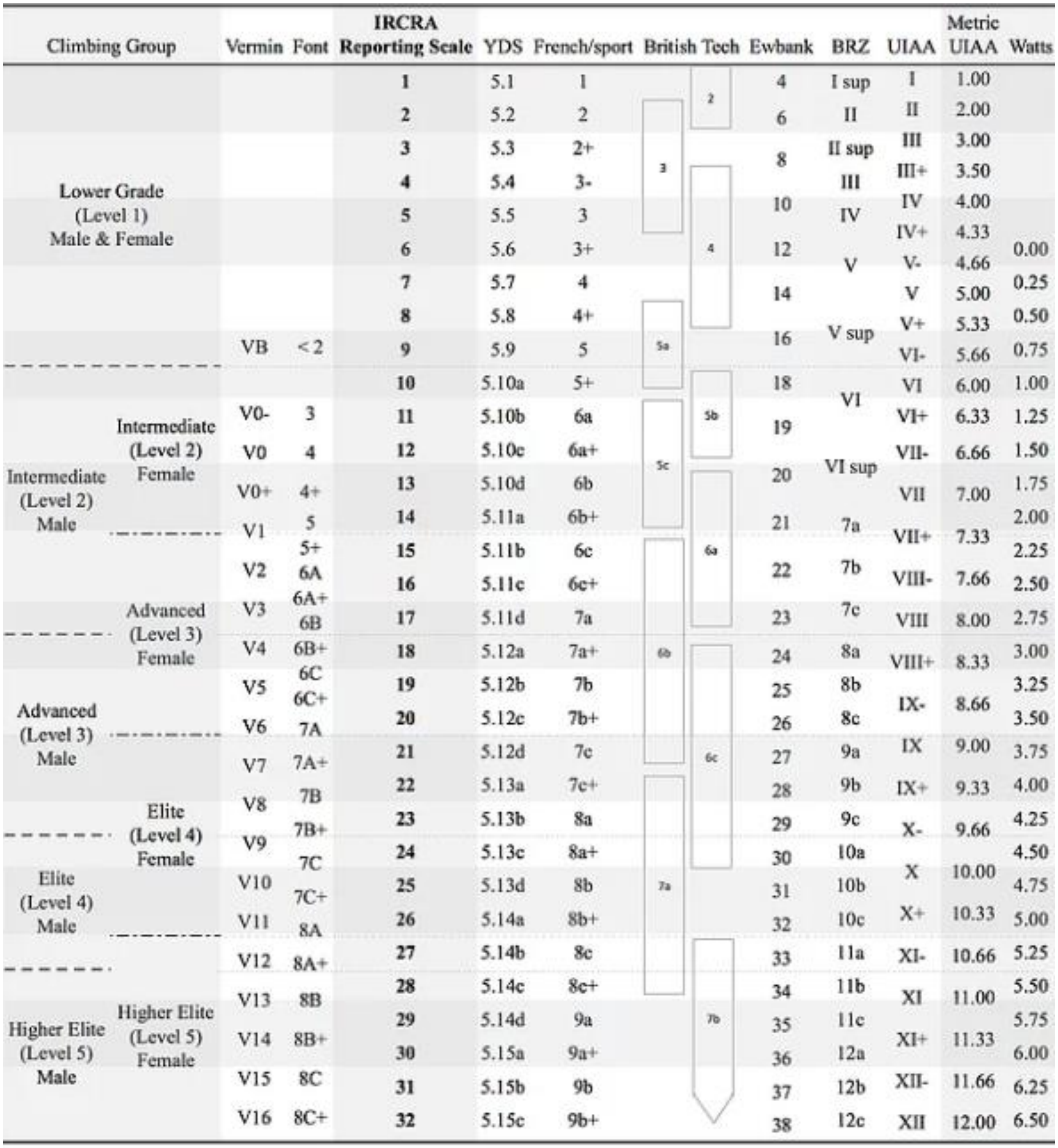
Difficulties in classifying climbing ability have been apparent in early research into rock climbing. Prior to the development of a scale to assess skill level (Draper, Brent, Hodgson, & Blackwell, 2009) earlier studies in rock climbing relied on subjective categories, using nomenclature that differed across studies, in the absence of a rating scale. For example, climbers as “novice” (Brent, Draper, Hodgson, & Blackwell, 2009), “recreational” (Bertuzzi, Franchini, Kokubun, & Kiss, 2007) or “experienced” (Phillip B. Watts et al., 2008). Draper et al (2009) was the first to establish a scale to assign skill level classifications.

Comparative Grading Scales (Draper et al. 2011, 2016)

After the scale first published by Draper (2009), the table was reworked. The researchers used the Delphi technique with more than 40 rock climbing experts and researchers across the world. Two tables were presented, one for both male and female climbers. The tables featured breaks between climbing ability based on grades across multiple scales of climbing difficulty.

Two previous researchers had developed numeric scales to represent climbing ability for statistical purposes (V. Schöffl, Morrison, Hefti, Ullrich, & Küpper, 2011; P. b. Watts, Martin, & Durtschi, 1993) which were included in the final tables. However, the scale by Watts **(**1993) starts at 5.6, not 5.1 as the YDS does. The researchers state that they understand the subjective nature of each category, however have accepted the scale to be accurate according to the multiple expert respondents.

In 2015, the International Rock Climbing Research Association (IRCRA) published a new table seen in figure 1 (Draper et al., 2016) with their own numeric scale for comparison. The new IRCRA scale has a number assigned to each difficulty in the most widely used grading systems: the YDS and French/sport scale. The IRCRA suggested all future climbing research use the scale published for clarity between studies. Previous work by Draper et al (2011) determined that both male and female climbers were able to accurately assess their skill level by simply self-reporting their highest redpoint ability. This scale will enable the current study to compare climbers according to type of climbing, and skill level. Recent publications have adopted the nomenclature of the new scale, and utilized the IRCRA numerical scale (Dykes, Johnson, & San Juan, 2019; Fryer et al., 2017, 2016; Limonta et al., 2018)**.**



Climbing Group		Vermin	Font	IRCRA Reporting Scale	YDS	French/sport	British Tech		Ewbank	BRZ	UIAA	Metric UIAA	Watts
Lower Grade (Level 1) Male & Female				**1**	5.1	1		2	4	I sup	I	1.00	
				2	5.2	2	3		6	II	II	2.00	
				3	5.3	2+			8	II sup	III	3.00	
				4	5.4	3-		4		III	III+	3.50	
				5	5.5	3			10	IV	IV	4.00	
				6	5.6	3+			12	V	IV+ V-	4.33 4.66	0.00
				7	5.7	4			14		V	5.00	0.25
				8	5.8	4+	5a				V+	5.33	0.50
		VB	< 2	**9**	5.9	5			16	V sup	VI-	5.66	0.75
Intermediate (Level 2) Male				**10**	5.10a	5+		5b	18	VI	VI	6.00	1.00
	Intermediate (Level 2) Female	V0-	3	**11**	5.10b	6a	5c		19		VI+	6.33	1.25
		V0	4	**12**	5.10c	6a+				VI sup	VII-	6.66	1.50
		V0+	4+	**13**	5.10d	6b		6a	20		VII	7.00	1.75
		V1	5	**14**	5.11a	6b+			21	7a			2.00
	Advanced (Level 3) Female		5+	**15**	5.11b	6c	6b		22	7b	VII+	7.33	2.25
		V2	6A	**16**	5.11c	6c+					VIII-	7.66	2.50
		V3	6A+ 6B	**17**	5.11d	7a			23	7c	VIII	8.00	2.75
Advanced (Level 3) Male		V4	6B+	**18**	5.12a	7a+		6c	24	8a	VIII+	8.33	3.00
		V5	6C 6C+	**19**	5.12b	7b			25	8b	IX-	8.66	3.25
		V6	7A	**20**	5.12c	7b+			26	8c			3.50
	Elite (Level 4) Female	V7	7A+	**21**	5.12d	7c			27	9a	IX	9.00	3.75
			7B	**22**	5.13a	7c+	7a		28	9b	IX+	9.33	4.00
		V8	7B+	**23**	5.13b	8a			29	9c	X-	9.66	4.25
Elite (Level 4) Male		V9	7C	**24**	5.13c	8a+			30	10a			4.50
		V10	7C+	**25**	5.13d	8b			31	10b	X	10.00	4.75
		V11	8A	**26**	5.14a	8b+			32	10c	X+	10.33	5.00
	Higher Elite (Level 5) Female	V12	8A+	**27**	5.14b	8c		7b	33	11a	XI-	10.66	5.25
Higher Elite (Level 5) Male		V13	8B	**28**	5.14c	8c+			34	11b	XI	11.00	5.50
				29	5.14d	9a			35	11c			5.75
		V14	8B+	**30**	5.15a	9a+			36	12a	XI+	11.33	6.00
		V15	8C	**31**	5.15b	9b			37	12b	XII-	11.66	6.25
		V16	8C+	**32**	5.15c	9b+			38	12c	XII	12.00	6.50

Figure 1: IRCRA Comparative Grading Scale (Draper et al., 2016)

Difficulty Rating

Sport climbing and bouldering are rated differently according to different regions of the world. The Yosemite Decimal System (YDS) is used primarily in the United States. The YDS uses a decimal number starting with “5,” indicating that a rope is required for safe ascent. The number that follows the “5” and a decimal point indicates the difficulty of the ascension. For example, a very easy climbing route would be rated a “5.1,” while the hardest route climbed so far is rated a “5.15d”. For ratings that are a “5.10” and beyond, a third scale is added in the form of “a-d” to provide further insight to the difficulty. For example, a “5.10a” would be easier than a “5.10b,” and so on. French Ratings range from 1-9 with an “a-c” and a “+” sign to indicate levels of difficulty. For example, a “6a” would be easier than a “6b+”. Bouldering uses the Vermin scale, with routes being denoted by a “v” followed by a number “0-16”. For example, a “v0” would be considered the easiest boulder rating, with a “v16” being the hardest boulder ever accomplished. Both of the scales have had grades added over the years as the sport has progressed both with lighter and more specialized equipment and better training facilities and programs.

Factors in Climbing Performance

Maximal Oxygen Uptake and Blood Lactate

Oxygen uptake, typically measured as VO2max, often increases during climbing (Baláš et al., 2014; España-Romero et al., 2009). The average $V02_{max}$ for lower level to elite climbers has been recorded to be from 50.5 mL·kg·min$_{-1}$ and 60.2 mL·kg·min (Seifert, Wolf, & Schweizer, 2018). While increased V02max is not an indication of climbing performance, climbers do seem to have a very high level of fitness. Factors such as the incline of the wall, speed of climbing and style of ascent can influence oxygen consumption (Sheel, Seddon, Knight, Mckenzie, & R. Warburton, 2003; Phillip B. Watts, 2004). The style of ascent is important in considering the aerobic contribution to climbing. Previous research found that as the time spent on the wall increases, percentage of VO_{2max} increases, from 33-38% in bouldering to 55.5-63.4% in treadwall climbing (Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; P. B. Watts & Drobish, 1998).

At the onset of climbing a route, heart rate increases disproportionately to oxygen consumption, a phenomenon, reported by Sheel et al. (2003), that is the result of the metaboreflex response. This metaboreflex response in climbing comes from the very high demand and ischemic nature of forearm flexion in rock climbing. The adaptation to this metaboreflex response manifests in increased rate of blood deoxygenation in the forearms, but not an increase in total blood flow (Fryer et al., 2015).

Neuromuscular adaptations

Forearm flexion in climbing is considered to be a series of isometric contractions, in order to maintain a position through the fingers against the force of gravity on the climber's body (Limonta et al., 2018; Phillip B. Watts, 2004). An increased rate of force development is important in these movements to enable the fingers to oppose gravity between movements (Fanchini et al., 2013; Levernier & Laffaye, 2017; Phillip B. Watts, 2004). Surprisingly, climbers do not have significantly greater grip strength than their non-climbing counterparts, but rather an increased strength-to-weight ratio (Macleod et al., 2007; Phillips, Sassaman, & Smoliga, 2012; Quaine et al., 2003; Vigouroux et al., 2006) and increased force time integrals (FTI) - a function of how much force is applied over time, which has been repeatedly used as a measure of climbing endurance (Fryer et al., 2015; Macleod et al., 2007; Phillips et al., 2012).

Technique and Climbing Economy

To reduce the strain on the forearms and to maximize these adaptations, technique should be practiced to improve climbing economy. Inexperienced climbers tend to perform more exploratory movements with their hands and spend less time ascending than experienced climbers (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Pijpers, Oudejans, Bakker, & Beek, 2006). This can lead to increased time on the wall and faster fatigue rates. In the course of a rock climber's career, a repository of experienced climbing motions is created. Over time, climbers develop an ability to identify similar groupings of holds and apply familiar motions to similar groupings of holds (Cordier, Dietrich, & Pailhous, 1996).

The improved climbing economy and practiced movement leads to multiple compounding physiological benefits. MacLeod (2007) found that muscle re-oxygenation provided by increased rest phases during climbing tests were indicative of climbing performance. Additionally, Fryer (2012) noted that advanced climbers spent more time in a recovery period on the wall than less experienced climbers, which in turn can increase forearm blood flow, andreduce metabolite build up and the accompanying metaboreflex (Sheel et al., 2003). Climbers were also found to have significantly increased reoxygenation of finger flexors and extensors compared to non-climbers (Fryer et al., 2015; Philippe et al., 2012). The result of an increased climbing economy is a reduction in VO_2 consumption and a lower heart rate increase in more experienced climbers during submaximal climbing (Baláš et al., 2014)**.**

Anthropometrics

Few anthropometric variables have been linked to climbing performance. An early study (Mermier, Janot, Parker, & Swan, 2000) measured multiple variables in climbers. Their findings found that anthropometric variables only accounted for 15% of variability in climbing performance, and 39% was explained by trainable characteristics. BMI and body fat percentage does not directly correlate with increased rock climbing performance, however some studies report lower BMI in climbers against controls (Limonta et al., 2018). The studies measuring body composition have conflicting results, an early study using dual energy x-ray absorptiometry (DEXA) found body fat percentage values of 4.7±1.3% and 10.7±1.7% in elite male and female climbers (Watts 1993). Another study (España-Romero et al., 2009) also used DEXA and found 25.2±3.6% body fat in female climbers ranging from advanced to elite, and 13.3±3.3% in male climbers ranging from intermediate to elite. The same study by Espana-Romero (2009) also did not find a statistical significance between advanced and elite male and female climbers in body fat percentage.

Forearm Musculature in Climbing

Multiple studies have measured strength, volume, circumference and other variables of the forearms of rock climbers. The most consistent finding in climbing performance is strength and performance adjusted for body weight in climbers (Fryer et al., 2017, 2015, 2016; Macleod et al., 2007; Philippe et al., 2012)**.** The size of the forearms of rock climbers have been measured multiple times (España-Romero et al., 2009; España-Romero & Watts, 2012; Fryer et al., 2017; Limonta et al., 2018; P B Watts et al., 2003). Total circumference of the forearms in advanced climbers was not found to be larger than controls (Macleod et al., 2007) however when controlled for body weight a significance was found. Total forearm circumference in elite climbers was found to be larger than controls (Esposito et al., 2009). The volume of the forearms in rock climbers over controls has not been statistically significant in young and adult climbers (España-Romero & Watts, 2012; Fryer et al., 2017; Watts et al., 2003) however when the volume was adjusted for bodyweight there was a statistical significance in adult climbers (España-Romero & Watts, 2012).

The endurance of the forearms in rock climbing have been repeatedly found to be a predictor of climbing performance (España-Romero & Watts, 2012; Philippe et al., 2012;

Quaine, Vigouroux, & Martin., 2003). From the intermittent isometric contraction in rock climbing and frequent ischemic conditions in the forearms, rock climbers develop an increased capacity to oxygenate the forearms (Fryer et al., 2017, 2015, 2016; Philippe et al., 2012)**.**

Measuring Muscle Muscle Thickness and Echo Intensity

Muscle CSA and Thickness

Muscular hypertrophy in the forearms is difficult to measure due to the small area in which multiple muscles are located. The three flexor muscles most notable in climbing research, the FCR, FDP, and FDS (Fryer et al., 2015, 2016; Macleod et al., 2007; Philippe et al., 2012) are all located in the anterior compartment of the forearm, including the other muscles: flexor pollicis longus (FPL), flexor carpi ulnaris (FCU), Pronator Teres (PT), and Palmaris Longus (PL) (Abe et al., 2018). Previous studies have conflicting results on circumferential and volume measurements of forearm hypertrophy in climbers (España-Romero & Watts, 2012; Esposito et al., 2009; Fryer et al., 2017; Limonta et al., 2018; Macleod et al., 2007; P B Watts et al., 2003)**.**

Muscle CSA has been reported to be a factor in force production (Fukunaga et al., 2001; Jones, Bishop, Woods, & Green, 2008). Previous research has deemed the assessment of muscle CSA to be a complicated and expensive measurement. Magnetic Resonance Imaging (MRI) has been shown to provide a complete view of each individual muscle and is considered to be a gold standard for CSA measurement (Engstrom, Loeb, Reid, Forrest, & Avruch, 1991). However, this instrument is expensive, and time-consuming, thus limiting its use in research.

Ultrasound, on the other hand, is an inexpensive and quicker method to measure muscle size. This still image from ultrasound measures can muscle thickness (MT), which is a linear measurement of the muscle from the muscle-bone and muscle-fat interface. The first measurement taken with ultrasound was by Ikai & Fukunaga (1968), who examined both muscle CSA and strength on 245 healthy humans. In a pilot study by Abe et al. (2018) MRI measurements of the forearm were compared to MT measurements with ultrasound in the same limb. The results indicated that MT and MRI measured CSA were highly correlated (r = 0.94 and r = 0.94) for forearm ulna MT and MRI-measured flexor and extensor CSA of the forearms.

Echo Intensity

While ultrasound can measure MT, a secondary assessment of muscle quality can be observed by measuring the echogenicity. Echogenicity refers to the darkness of muscle on an ultrasound image, measured by a gray-scale analysis by a separate program such as Adobe CS or Image J (Li et al., 2012; Stock, Mota, Hernandez, & Thompson, 2017). Muscle tissue in ultrasound is much darker in color than fat and connective tissue when measuring echogenicity, the darkness of each pixel is assessed, and a value, or echo intensity (EI), can be assigned to the muscle in question which represents the amount of connective tissue and fat in the muscle (Mayans, Cartwright, & Walker, 2012)**.** EI is typically associated with changes in muscle with age and neuromuscular disorders, with higher values being associated with lower muscle quality due to fat and connective tissue infiltrating the muscle (Fukumoto et al., 2012; Watanabe, Ikenaga, Yoshimura, Yamada, & Kimura, 2018).

Few studies have examined EI to measure performance in healthy adults and children (Kleinberg, Ryan, Tweedell, Barnette, & Wagoner, 2016; Stock et al., 2017)**..** A previous study by Li et al (2012) compared EI of the median nerve and surrounding muscles in forearms of young (<30 years old) and old populations (>60 years old), finding that the young population had significantly lower EI values than the older population (p<.0005). Although the study Li et al

(2012) examined some of the muscles utilized in rock climbing, no studies, however, have compared EI of forearm muscles in young adult climbers and non-

Summary of Previous Literature

From the previous literature, it is apparent that rock climbers consistently demonstrate increased strength to weight ratios for measurements of performance and anthropometrics. The physiology of rock climbers tends to lean towards a leaner physique, with greater endurance in gripping through the forearm flexors, made possible by greater oxygenating capabilities. Previous studies on the hypertrophic response to climbing has found an increase in forearm volume and circumference to weight ratio against controls, with conflicting results between studies. The primary muscles responsible for the finger and wrist flexion in rock climbing are the FDP, FDS and FCR, which are all located in the anterior compartment of the forearm, which have typically been measured via Magnetic Resonance Imaging (MRI). Due to logistic issues, time, and cost, MRI may not be feasible to utilize in a research setting, however, ultrasound has been identified as a potential alternative to MRI. Although research suggests a high degree of measurement agreement between MRI and ultrasound, no studies to date have examined the muscle thickness of forearms in young adult climbers versus non-climbers. The proposed study will address that gap in the literature, identifying whether differences occur to a greater extent in climbers compared to a non-strength trained population. Such findings will assist with the development of more specific training protocols for individuals competing in the sport of rock climbing.

CHAPTER THREE: METHODOLOGY

Study Design

The present study was a cross-sectional, observational study that took place at the Neuromuscular Plasticity Lab at the University of Central Florida.

Participants

A total of 34 young adults, ages 18 – 35 years, were recruited to participate in the current study. Participants will be recruited from local climbing gyms, word-of-mouth and social media posts. 5 participants were excluded due to failure to meet the inclusion criteria.

Inclusion/Exclusion Criteria

To be eligible for this study, individuals had to be between 18 – 35 years of age, with a body mass index (BMI) of >18 kg/m^2 and < 25 kg/m^2. Two sets of criteria were established to determine whether participants can be included in the study as either climbers or controls. Individuals first reported whether or not they had recent climbing experience. Any climbing experience recorded for a minimum of the most recent six months qualified an individual to participate as a climber. Climbers then reported their skill in climbing by estimating the hardest rated climb they can perform, which has been found to be an accurate measurement of climbing ability (Draper et al., 2011). Climbers were excluded if they have had any climbing related injuries that resulted in a hiatus from climbing for at a least 2 weeks in the last 6 months. If individuals had reported no climbing experience, they were classified as controls. Controls reported an average of <1 resistance training sessions per week and not exceeding a moderate intensity in the most recent 6 months.

Climbing Experience

Climbing experience was categorized based on the self-reported ability chart outlined by Draper (2016) in figure 1 by their sport climb ability. Only recruited climbers were asked to rate their climbing ability, and whether they identify themselves as a “boulderer” or “sport climber”. Based on this information, participating climbers were categorized into two categories of skill level: intermediate (redpoint of 5.10a-5.11d for males and 5.10a-5.11a for females) and advanced (5.12a-5.13b for males and 5.11b-5.12c for females). Participants who were “non-climbers” served as the control condition and did not complete these climbing-based questions.

Measures

Demographic Information

Participants were asked to complete a standard demographic questionnaire, containing items age, gender, and race.

Anthropometrics

Participants were instructed to show up to the lab in a state of euhydration. After the informed consent, participants provided a urine sample for urine-specific gravity assessment with a hand-held refractometer (Atago Master-Sur/Na, Tokyo, Japan) to ensure hydration status as defined by a USG value of <1.020. If participant USG was >1.020 they were instructed to drink water until another test revealed a state of euhydration.

Participants were weighed on a physician’s scale, and their height measured with a stadiometer. After height and weight measurements, participants were asked to lie on their backs on a padded table for a minimum of 3 minutes to restore fluid equilibrium prior to bodyfat measurements. Upper limb and total body fat percentage were then measured via bioelectrical spectroscopy (BIS) (SFB7, ImpediMed Inc., Carlsbad, Ca, USA). Single use electrodes were placed on the dominant hand, shoulder and foot. One electrode was placed both on the wrist between the head of the ulna and radius, and between the malleoli on the foot, and another electrode was placed 5 centimeters distally to both. Another electrode was then placed on the acromion process. All electrode sites were shaved with a disposable razor and rubbed with an alcohol wipe to improve electrode contact. Total body fat was recorded three times and the average of the three was used for analysis.

After each participant's bodyfat percentage was measured, participants extended the measured arm straight out to the side and the length of their arm from the electrode on the acromion process and wrist was measured. Their arm was then placed back at their side, and the length of the forearm was measured from the proximal head of the ulna, to the distal head of the radius (Abe et al., 2015). The thickest part of the forearm flexors was made by visually inspecting for a peak in the musculature of the medial aspect of the forearm with the participants arm straight at their side and hand supinated. A circumference measurement was made of the forearm at this peak, and a small mark on the skin was made with a marker for later ultrasound MT measurement. The same was done at 50% of the distance of the length measurement for EI measures.

Ultrasound

After the weighing and body fat measurement, participants were asked to lie down on a padded table, with their dominant forearm supinated. Ultrasound images were taken in B-mode with a portable imaging device (GE Logiq e BT12, GE Healthcare, Milwaukee, Wisconsin) and a multi-frequency linear-array probe (12 L-RS, 5-13 MHz, 38.4-mm field of view; GE

Healthcare, Wauwatosa, Wisconsin). The depth for all MT measurements was kept at 7cm for all participants, and 3cm for all EI measurements. A generous amount of silicone transmission gel was be applied to facilitate conduction between the ultrasound probe and the surface of the skin, as well as to preserve any curvature of the forearm to keep measurements unaltered. Three images at both marked sites of the forearm will be taken and the average of the three were used for analysis.

The distance from the ulna and radius to the peak of the FCR for MT Ulna and brachioradialis for MT Radius was measured. Figure 2 illustrates the technique used to assess this distance. In cases where the peak of the FCR was not immediately above the ulna, a line perpendicular to the ulna was drawn and the thickness of the flexors below the peak was measured to that line (illustrated in Figure 3). Mean EI of the flexor muscles in the forearm surrounding the median nerve was analyzed with 40x40 pixel boxes in each muscle (Li et al., 2012) (Figure 4). Three still images were taken for EI measurements. Ultrasound pictures were analyzed with ImageJ software (Version 1.52 National Institutes of Health, Bethesda, MD, USA).

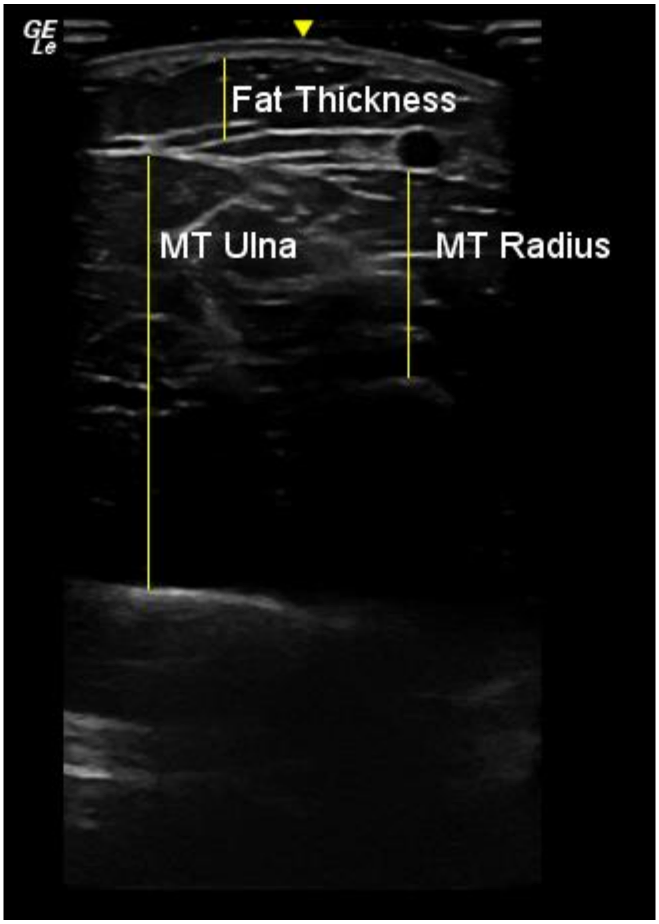


Figure 2: Female Climber Measurements with Fat Thickness

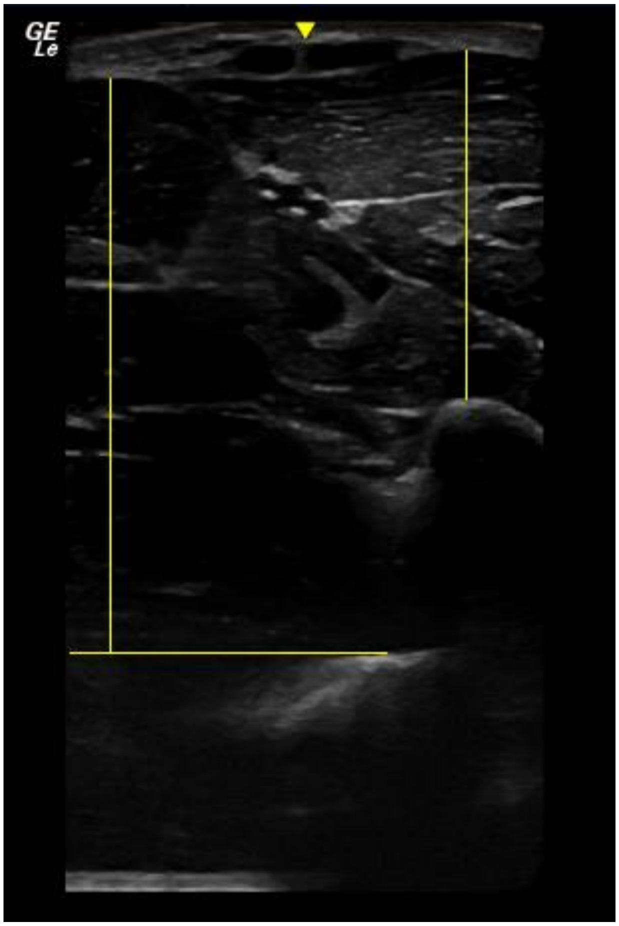


Figure 3: Male Climber with Alternate Muscle Alignment

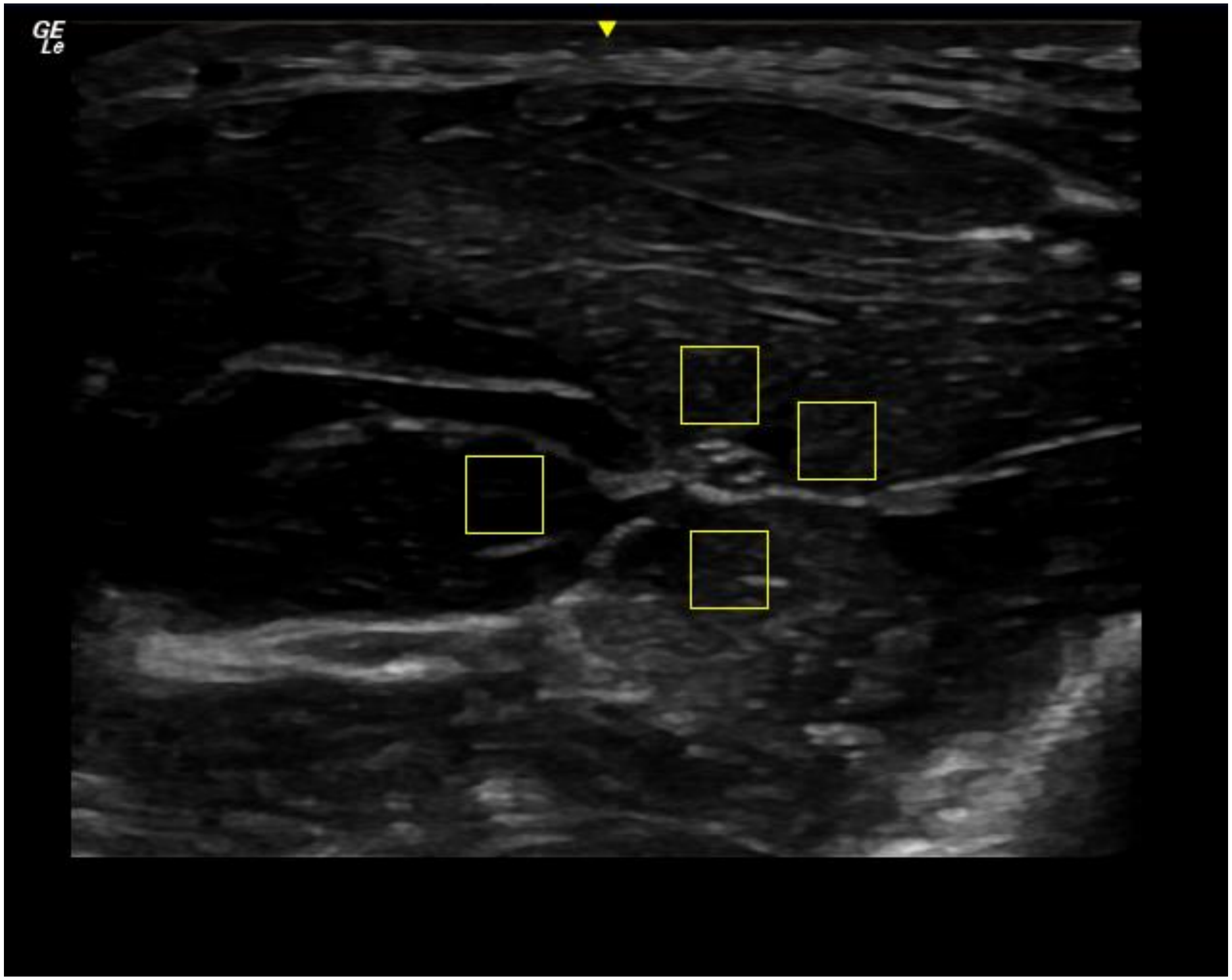


Figure 4: Echo Intensity Measurements in a Climber

Statistical Analysis

Descriptive statistics were conducted for all demographic and anthropometric characteristics for both climbers and controls. Independent samples t-tests were used to measure the differences among muscle thickness, fat thickness and mean EI between climbers and non-climbers. Exploratory analyses (1-way ANOVA) was conducted to compare differences in muscle thickness, fat thickness, and mean EI among sport climbers, boulders, and non-climbers., as well as gender differences between climbers and non-climbers. ANOVA was also conducted to examine differences in muscle thickness and EI among climbing skill level (non-climber, intermediate, advanced). Post hoc tests were conducted to further identify where group differences exist. Pearson Correlations were used to analyze relationships between forearm flexor muscle thickness (MT Ulna and MT Radius) and climbing ability. The data collected was analyzed using IBM SPSS Statistics 24 with a significance level set at $p<0.05$.

CHAPTER FOUR: RESULTS

Participants

A total of 33 participants were included in this study. Initially, 38 participants were recruited to take part in the study, however, 5 were excluded during the screening process due to a body mass index (BMI) that fell outside the study's BMI inclusion range. Table 1 displays demographic characteristics for both climbers and controls. No significant differences in demographic characteristics were found.

Table 1: Participant Demographics

Factors	Climbers (n=22)	Non-climbers (n=11)
Age, M (SD)	22.23 (3.01)	21.91 (1.97)
Males, N (%)	15 (68%)	6 (55%)
Caucasian, N(%)	12 (57%)	6 (55%)
BMI, M (SD)	21.77 (3.23)	22.62 (2.28)
Advanced climbing skill level, N (%)	11 (50%)	N/A
Years of climbing experience, M (SD)	2.44 (1.24)	N/A
IRCRA scale[a] , M (SD)	16.1 (2.83)	N/A
Sport Climbers, N (%)	17 (77%)	N/A

*$p<0.05$

[a] International Rock Climbing Research Association

Ultrasound Measures

Climbers had a significantly lower body fat percentage compared to controls (19.14% vs 30.02%, p<.0001). For muscle thickness measures at the ulna, climbers had significantly thicker muscle than controls (4.23 vs 3.61, p<.0001). Similarly, for muscle thickness at the radius, climbers had significantly thicker muscle measures compared to controls (2.32 vs. 1.84, p<.0001). Table 2 presents the means and standard deviations for all variables. Data was missing for fat thickness as there was no measurable layer. Due to measurement error, 8 participants were missing echo intensity values.

Table 2: Comparison of Ultrasound Measures Between Climbers & Controls

Factors	Climbers	Controls
Body fat %, M (SD)	19.14 (6.99)	30.02% (7.6)***
Muscle Thickness at ulna	4.23 (.39)	3.61 (.6)***
Muscle Thickness at radius	2.32 (.39)	1.84 (.31)***
Fat Thickness[a]	.3 (.21)	.56 (.28)+
Mean Echo Intensity[b]	14.96 (3.89)	12.15 (6.86)

+p<.1; *p<.05; **p<.01; ***p<.001

[a] Missing participant data (Climber, n=14; Non-climber, n=6)

[b] Missing participant data (Climber, n=7; Non-climber, n=1)

Exploratory Results

Types of Climbing

The results from the ANOVA indicate that both boulders and sport climbers had significantly lower percentage of body fat compared to controls (p=.004). No differences in body fat percentage was observed between boulders and sport climbers. Boulders and sport climbers had significantly thicker muscle at the ulna compared to controls (p=.0008), and significantly thicker muscles at the radius compared to controls (p=.004). No differences between boulders and sport climbers were found for either muscle thickness at the ulna or radius. Additionally, no differences in either fat thickness (p=.22) or EI (p=.46) were observed among boulders, sport climbers, and non-climbers. Table 3 presents the comparison of measures across the three groups.

Climbers vs Controls Across Gender

The results from the ANOVA indicate that male climbers had a significantly lower body fat percentage than male and female non-climbers, while female climbers had a significantly lower body fat percentage compared to female non-climbers (p<.0001). No differences existed between male and female climbers or male and female non-climbers. For muscle thickness at the ulna, male climbers had significantly thicker muscle compared to male non-climbers, female climbers, and female non-climbers, while female climbers had significantly greater muscle thickness compared to female non-climbers (p<.0001). For muscle thickness at the radius, male climbers had significantly thicker muscle compared to male and female non-climbers, while female climbers had significantly greater muscle thickness compared to female non-climbers (p<.0001). For fat thickness, male non-climbers had significantly greater values compared to female climbers and non-climbers (p=.004). No differences in EI were observed among male and female climbers and non-climbers. Table 4 presents that comparison of measures across male and female climbers and non-climbers.

Skill Level

The results from this analysis indicate that advanced climbers had a significantly lower body fat percentage than non-climbers (p=.0002), while both intermediate and advanced climbers had greater muscle thickness at both the ulna (p=.0007) and radius (p<.0001) compared to non-climbers. No differences in body fat or muscle thickness existed between the intermediate and advanced climbers. No differences existed for EI among the three groups. Table 5 presents the comparison of measures among the non-climbers. Intermediate, and advanced climbers.

Table 5: Comparison of Ultrasound Measures Among Skill Level

Factors	Intermediate (n=11)	Advanced (n=11)	Controls (n=11)
Body fat %, M (SD)	22.48% (7.13)	15.47% (4.85)	29.51% (7.34)***
Muscle Thickness at Ulna	4.13 (.48)	4.44 (.16)	3.51 (.56)***
Muscle Thickness at radius	2.1 (.39)	2.56 (.19)	1.79 (.29)**
Mean Echo Intensity	16.78 (3.7)	12.53 (2.81)	12.15 (6.86)

Correlational Analysis

Results from the correlational analysis conducted with climbers indicated that the IRCRA scale was significantly correlated with years of climbing experience (r=.6, p=.004), forearm muscle thickness at the ulna (r=.6, p=.004), and forearm muscle thickness at the radius (r=.79, p<.0001). A significant, negative correlation was found between the IRCRA scale and body fat percentage (r=-.7, p=.0004). No other significant correlations were found among variables.

Results from Independent t-tests

Table 3: Comparison of Ultrasound Measures Among Type of Climbing Experience

Factors	Boulder (n=5)	Sport (n=16)	Controls (n=9)
Body fat %, M (SD)	16.89% (5.4)	19.85% (7.42)	29.51% (7.34)**
Muscle Thickness at Ulna	4.46 (.2)	4.22 (.42)	3.51 (.56)***
Muscle Thickness at radius	2.47 (.16)	2.27 (.43)	1.79 (.29)**
Fat Thickness	.36 (.07)	.28 (.24)	.56 (.28)
Mean Echo Intensity	14.39 (4.92)	15.19 (3.69)	12.15 (6.86)

*p<.05; **p<.01; ***p<.001

Table 4: Comparison of Ultrasound Measures Among Male and Female Climbers and Controls

Factors	Male Climbers (n=15)	Male Controls (n=5)	Female Climbers (n=6)	Female Controls (n=4)
Body fat %, M (SD)	15.82% (4.95)	25.7% (4.24)	27.43 (3.34)	35.4% (7.73)***
Muscle Thickness at ulna	4.47 (.2)	3.95 (.56)	3.8 (.32)	3.19 (.34)***
Muscle Thickness at radius	2.52 (.23)	2.03 (.27)	1.82 (.12)	1.61 (.19)***
Mean Echo Intensity	14.74 (4.2)	9.31 (2.19)	15.5 (3.5)	14.99 (8.99)

*p<.05; **p<.01; ***p<.0010

CHAPTER FIVE: DISCUSSION

The purpose of this study was to measure hypertrophic response to rock climbing in the forearms of non-elite level rock climbers versus non-climbers. Elite climbers have been shown to have larger circumference of forearms (Esposito et al., 2009), however the brachioradialis is a prominent muscle involved in rock climbing (Boccia et al., 2015) that adds substantial size to the forearm unrelated to the finger flexors. The present study utilized a previously unused method of measuring differences in finger flexor specific thickness in rock climbers using ultrasound via muscle thickness.

The results provided support for the hypothesis that intermediate and advanced rock climbers have thicker flexor muscles than controls. Previous findings demonstrate that climbers had significantly greater forearm volume when adjusted for bodyweight (España-Romero & Watts, 2012, however, the current study found an increase in muscle thickness in climbers compared to non-climbers without adjusting for bodyweight. When observing forearm circumference of previous studies, Macleod et al. (2007) found no difference between climbers (average ability of 5.12a) and controls (27.8±1cm in climbers and 27.6±1.6cm in controls) and Limonta et al. (2018) reported circumferences of 28.7±.3cm in advanced climbers (5.12a-5.12d) and 29.8±.6cm in elite climbers (5.13b-5.14a), demonstrating the trending relationship towards larger forearm circumferences and increased climbing ability. The present study expands on these prior findings by comparing self-reported IRCRA scales and muscle thickness, finding a positive relationship between IRCRA scales and muscle thickness at both the ulna and radius site.

Interestingly, while the exploratory findings identified differences in MT at both the ulna and radius in sport climbers vs. non-climbers and boulderers vs. non-climbers, no differences between sport climbers and boulderers were observed. A possible reason could be due, in part, to the limited number of participants who identified themselves as boulderers. Additionally, a few participants reported an advanced bouldering ability with an intermediate sport climb, which may affect the interpretation of the results. The categorization of participants was based on their sport climb due to the 1-1 relationship with the IRCRA scale. The purpose of having participants report the distinction between their preference of climbing discipline was to give an idea of the type of climb they performed more often. Boulderers climb much shorter and higher intensity problems compared to sport climbers (Fryer et al., 2017), with evidence indicating boulderers have improved maximal voluntary contraction values over sport climbers and controls, and faster time to fatigue than the control group.

This was the first study to assess echo intensity (EI) in young adult climbers and non-climbers. However, the results from this study did not find any differences in EI among climbers and non-climbers, thus our initial hypothesis predicting lower EI values in climbers was not upheld. Ultrasound has not been utilized in the past to assess EI, with one of the challenges of this technique being that, the individual flexor muscles of the forearm are hard to identify on ultrasound except for the FCR. The current study attempted to follow the procedures provided by Li et al. (2012), who outlined a method to record EI for the FDS and the FDP. Their study utilized doppler ultrasound instead of B-mode, and a six second video was recorded for optimal brightness as opposed to 3 still images recorded in this study. Unlike Li et al. (2012), the values recorded for climbers in the current study appeared to have a high degree of variability, with a value of 14.9±3.89, which appeared to be substantially lower than the EI values reported by Li's study (2012).This could be due to measurement error, and therefore, it is suggested that future studies should examine similar studies to determine the precise procedures and training necessary to assess factors such as muscle quality utilizing ultrasound, a cost-effective and non-invasive measure of muscle quality.

As predicted in our initial hypotheses that climbers would have thicker flexor muscles, there were also significant associations were found between the IRCRA scale, climbing experience, and muscle thickness at both the radius and ulna in climbers. This shows that climbers may experience muscular hypertrophy initially after training, which positively corresponds to the advancement in climbing skill level in the early stages of climbing.

Strengths and Limitations

The current study had several strengths worth noting. The present study utilized ultrasound, a more feasible and direct measure of muscle thickness, and had the unique benefit of being able to isolate the specific muscles relevant to rock climbing. Measures such as bodyfat percentage were assessed by a valid, objective measurement rather than self-reported height and weight, seen in previous studies. Hydration of the participants also assessed, therefore controlling for any effects that dehydration could have on physiological measures, such as body fat percentages and the effect blood volume may have on MT measures. Additionally, the skill levels of climbers were primarily at intermediate or advanced levels, rather than elite, which may be more representative of the general climbing population.

Despite the strengths of the current study, several limitations should also be noted. The sample size was small, which limits our ability to generalize these results to a larger population. The challenge of sample size in the current study may be due, in part, to the strict inclusion/exclusion guidelines the study team agreed on, which were made in an effort to get as accurate a measurement as possible. The exclusion criteria in this study could be reviewed for future work on how strict they were. A hiatus of ~2 weeks and recent climbing reported at <2-3 times per week would have a debatable influence of the hypertrophy in the forearms as long as intermittent breaks or other life issues that could interfere with weekly climbing didn't result in a severe detriment of their abilities and could include more casual climbers in these studies.

Climbing ability and skill level was based off of participant self-report which is prone to bias (Draper et al., 2011), however, self-reported ability for climbing is the most common method known for assessing skill level. Finally, as noted previously, the high degree of variability in EI measurements was unexpected and may be a factor of measurement error. As this was one of the first studies to examine EI among a sample of climbers and non-climbers, more work needs to focus on using ultrasound to examine whether this method may accurately assess muscle quality in a young adult, athletic population.

Implications

Several implications can be drawn from the current study. The findings from this study could pose to target training for newer climbers. Thicker flexor muscles were evident even in intermediate climbers over controls, it could be suggested for newer climbers to focus training their forearms, however care should be taken in consideration for the connective tissue in the fingers. Such training techniques could improve climbing performance in newer climbers and may even help to reduce climbing-related injuries, that typically result from overuse and strain of the connective tissue in climbers (Garcia, Jaramillo, & Rubesova, 2018). Thickness increases in both the flexor muscles and the connective tissue can possibly be tracked to identify any weaknesses a climber may develop. Measurements for both MT ulna and radius had very high reliability (.99).

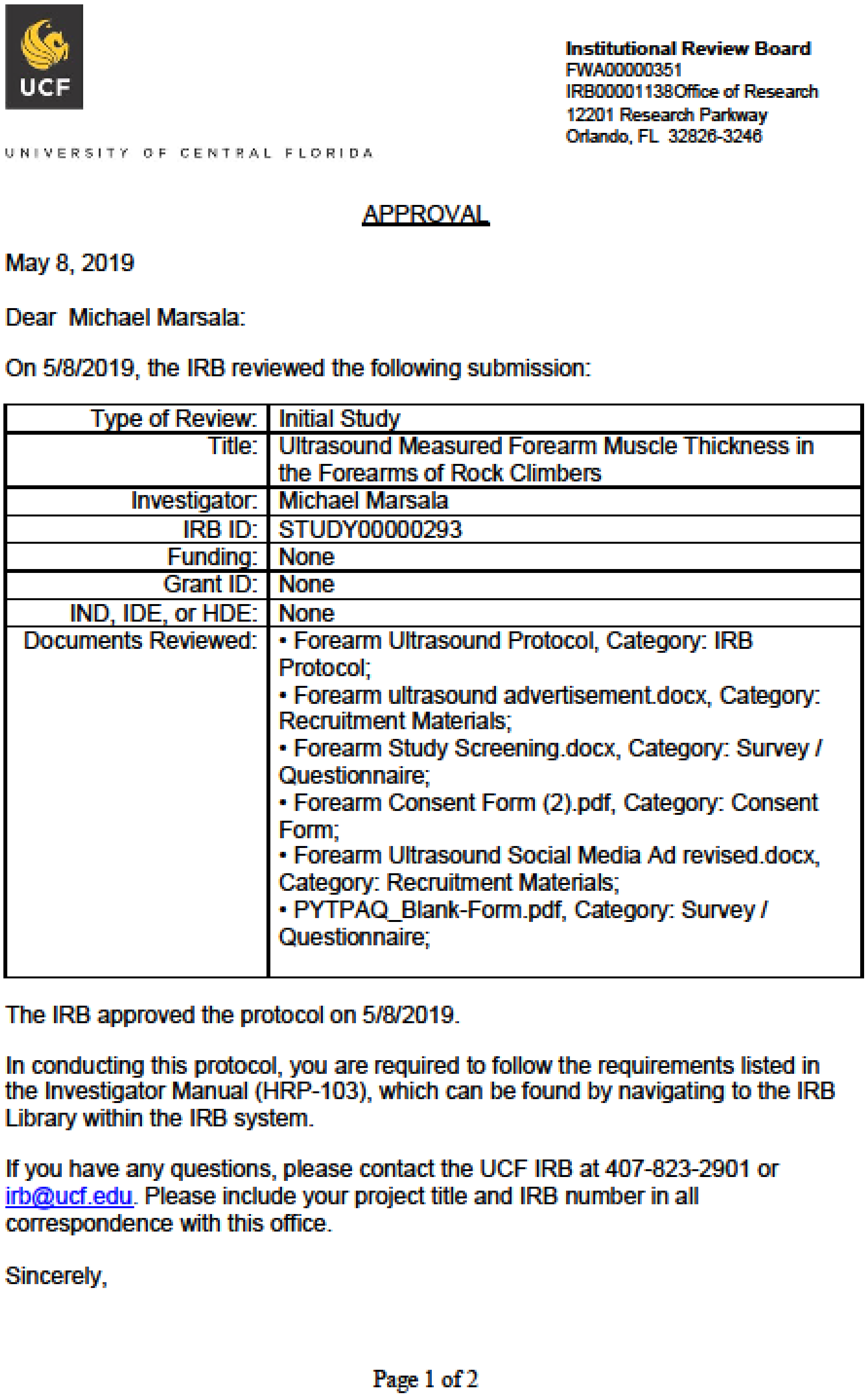
Future Directions

Subsequent studies should consider utilizing the methods used in this study to stratify values for different levels of climbing and measure improvements with different training modalities. Future studies should include a larger sample size to allow comparisons between genders and type of climbing (sport vs. boulder), which could be used to develop specific training regimens for climbers. EI measurements can also be standardized, with more precise measurement techniques necessary for accurate EI measures. It was noted during this study that the FCR is very apparent for most of the forearm and is very prominent at the flexor peak in the forearms of rock climbers, ultrasound can be used to directly measure the CSA and EI of the FCR of rock climbers. With a larger sample, it would be possible to stratify muscle thickness among different levels of climbing. The MT of the finger flexors and also be matched with adaptations to the tendons and pulleys in the fingers in an effort to reduce the chance for injury during training.

Conclusion

The findings in this study present new evidence to the amount of hypertrophy that rock climbing alone causes in the forearms of athletes. With noticeable differences in thickness at intermediate and advanced levels, it can be suggested that newer climbers can aim to train for hypertrophy in their forearms to help with increasing their climbing ability on top of already measured vascular and oxidative adaptations. Future work should be done to examine whether rock climbing and related training are responsible for the increase in muscle thickness found in climbers.

APPENDIX A: APPROVAL LETTER



UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

APPROVAL

May 8, 2019

Dear Michael Marsala:

On 5/8/2019, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title:	Ultrasound Measured Forearm Muscle Thickness in the Forearms of Rock Climbers
Investigator:	Michael Marsala
IRB ID:	STUDY00000293
Funding:	None
Grant ID:	None
IND, IDE, or HDE:	None
Documents Reviewed:	• Forearm Ultrasound Protocol, Category: IRB Protocol; • Forearm ultrasound advertisement.docx, Category: Recruitment Materials; • Forearm Study Screening.docx, Category: Survey / Questionnaire; • Forearm Consent Form (2).pdf, Category: Consent Form; • Forearm Ultrasound Social Media Ad revised.docx, Category: Recruitment Materials; • PYTPAQ_Blank-Form.pdf, Category: Survey / Questionnaire;

The IRB approved the protocol on 5/8/2019.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Page 1 of 2

Racine Jacques, Ph.D.
Designated Reviewer

APPENDIX B: CONSENT FORM

UNIVERSITY OF
CENTRAL FLORIDA

Title of research study: *Ultrasound Measured Forearm Muscle Thickness in the Forearms of Rock Climbers*

Investigator: ***Michael Marsala***

Key Information: The following is a short summary of this study to help you decide whether or not to be a part of this study. More detailed information is listed later on in this form.

Why am I being invited to take part in a research study?

We invite you to take part in a research study because you are a healthy young adult between the ages of 18-35 and either a rock climber who has reported consistent climbing as defined by an average of 23 climbing sessions per week for the last 6 months, or you have no climbing experience and have no reported consistent upper body resistance training in the last 6 months.

Why is this research being done?

This research is being done to measure the thickness of the flexor muscles in the forearm. The goal is to add evidence to the literature of the importance or lack of technique in rock climbing in non-elite levels.

How long will the research last and what will I need to do?

We expect that you will be in this research study for a maximum of 45 minutes.

You will be asked to show up at a scheduled time of your choosing for hydration assessment, anthropometric measurements and an ultrasound of your dominant forearm.

More detailed information about the study procedures can be found under ***"What happens if I say yes, I want to be in this research?"***

Is there any way being in this study could be bad for me?

The risks to participation are minimal and do not exceed the risks associated with activities found in daily life.

Will being in this study help me any way?

There are no benefits to you from your taking part in this research. We cannot promise any benefits to others from your taking part in this research.

What happens if I do not want to be in this research?

Your participation in this study is voluntary. You are free to withdraw your consent and discontinue participation in this study at any time without prejudice or penalty. Your decision to participate or not participate in this study will in no way affect your continued enrollment, grades, employment or your relationship with UCF or the individuals who may have an interest in this study.

Your alternative to participating in this research study is to not participate.

Detailed Information: The following is more detailed information about this study in addition to the information listed above.

What should I know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Who can I talk to?

If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team: at Michael.marsala@yahoo.com or at: 407-453-2517

Or Dr. Jeanette Garcia at Jeanette.garcia@ucf.edu or 407-823-3207

This research has been reviewed and approved by an Institutional Review Board ("IRB"). You may talk to them at 407-823-2901 or irb@ucf.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research subject.
- You want to get information or provide input about this research.

How many people will be studied?

We expect 80 people will be in this research study.

What happens if I say yes, I want to be in this research?

You will be scheduled to arrive at the Neuromuscular Plasticity Laboratory at the University of Central Florida. The study will be comprised of a single visit no more than 30 - 45 minutes. Upon entering the lab, you will be asked to provide a urine sample for hydration assessment. If you are not hydrated, you will be asked to consume water until a following urine test proves otherwise. After the urine sample is provided, you will be given a short questionnaire to fill out for demographic reasons and to report your climbing ability and preferences. You will also fill out the Past Year Physical Activity Questionnaire. After that your height and mass will be measured on a scale, and you will lie down on a padded table and remove your shoes (and socks) and lie still for 3 minutes. After this time, a series of electrodes (BIS) will be placed on your wrist, shoulder and foot. The surface of the skin where these electrodes are placed will be shaved and cleaned with an alcohol wipe to improve conduction. An unnoticeable electric current will be used to measure body fat percentages. These machines are widely used commercial products with FDA approval.

After the BIS measurement, your forearm circumference and length will be measured. At the thickest part of the forearm, between your elbow and wrist, a mark will be made. Another mark will be made at 50% of the distance between your elbow and wrist. A generous amount of silicon gel will be applied to the surface of the forearm to improve the sound conduction for the ultrasound images. After this, a Bmode ultrasound measurement will be taken 3 times in the same spot at each mark. After this your participation will be concluded.

What are my responsibilities if I take part in this research?

If you take part in this research, you will be responsible for arriving on time to your scheduled appointment and following the directions of the research team.

What happens if I say yes, but I change my mind later?

You can leave the research at any time it will not be held against you. If you back out of the study before the conclusion, any data collected will be destroyed.

What happens to the information collected for the research?

Efforts will be made to limit the use and disclosure of your personal information, including research study to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. No identifiable information will be collected. Data collected will be stored for a minimum of 5 years on a password protected laptop.

Signature Block for Capable Adult

Your signature documents your permission to take part in this research.

Signature of subject	Date
Printed name of subject	
Signature of person obtaining consent	Date
Printed name of person obtaining consent	

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