Examination of Individual Finger Flexor Force Production and Performance Limiting Factors in Rock Climbing

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Glossary

Ape index: Ratio of arm span to body height.

Elite climber: Male — 24+ (IRCRA scale); Female — 21+ (IRCRA scale)

Climbing-specific finger strength: Measured without the opposition of the thumb or thenar zone of the hand.

Climbing-specific hanging test position: "[The climber] suspends him or herself from the hand hold adjusting the last phalanx of the fingers according to its characteristics" The wrist is also superior to the elbow. (Morenas, del Campo, Román, Horrillo, & Navarro, 2013, pg. 3)

Climbing-specific VO_2: Measured with the use of a special climbing ergometer to assess VO_2 during climbing. (Watts 2004)

Competition formats:

On-sight: The competitors take turns, one at a time, attempting the same routes. This ensures that they will have no prior knowledge of the route during their turn.

Red-point: All competitors enter a bouldering area together with many different routes they can try. They are given a set time limit to get the highest score possible.

Disciplines of climbing:

Bouldering: Characterized by shorter routes without the use of protection such as ropes or harnesses.

Sport climbing (a.k.a. lead climbing): Characterized by longer routes with the use of ropes and harnesses where the climber affixes themselves into artificial anchor points as they ascend the route.

Fingertip pulp: Fleshy skin extending from the end of the distal phalange to the tip of the finger. (Bourne, Halaki, Vanwanseele, & Clarke, 2011)

Grading scales:

Yosemite decimal system (YDS): "uses the numeral 5 to indicate ''free'' climbing, where no artificial means are employed to aid progress, followed by a ''decimal point'' and a second numeral to indicate the overall difficulty of the route. This scale currently extends from 5.0 (easiest) to 5.15 (most difficult). Letter subdivisions of a, b, c and d are used from the 5.10 level upward to indicate further gradients of difficulty." (Watts 2004, pg. 361)

V-scale: Scale used for bouldering that increases chronologically with the difficulty of the route. This scale currently extends from V0 (easiest) to V17 (hardest). Pluses and minuses can also be used to further delineate the routes.

IRCRA scale: Universal scale for the conversion of climbing grades to be used in a research setting.

Grip types:

Crimp grip: Hyperextension (210°) at the DIP joint, 100° flexion at the PIP joint, and 160° at the MCP joint. (Quaine, Vigouroux, & Martin 2003)

Full Crimp: Same as crimp grip, but with the thumb placed atop the index finger. (Bourne, Halaki, Vanwanseele, & Clarke, 2011)

Half-crimp grip: The DIP joint is flexed at 180°, the PIP at 90°, and the MCP at 180°.

Slope grip: The DIP, PIP and MCP are flexed at 150°, 160° and 150° respectively. (Quaine, Vigouroux, & Martin 2003)

Hold types:

Crimp: Small edge usually not larger than one phalange.

Edge: Flat surface that the climber can grasp with all four fingers.

Pinch: A hold where the thumb is in opposition the four fingers.

Pocket: Holds with holes in them that can only accommodate one to three fingers.

Sloper: A hold that must be grabbed with the whole palmer side of the hand due to its sloping nature.

Rock climbing: A sport that involves climbing rock faces. The use of ropes may or may not be present.

Route: The path that a climber follows in order to complete a climb.

On-sight: "Climbing an unknown route. The climber is not allowed to watch someone else do the route or obtain information about the route." (Schweizer & Furrer 2007, pg. 212)

Red-point: "Climbing a known route of about 15 to 25 m height. The route has to be climbed from the bottom to the top without technical aid or resting at an artificial point like a bolt. The grade of difficulty is usually so high that a successful ascent is not possible on their first try." (Schweizer & Furrer 2007, pg. 212) Obtaining a red-point send on given route can take days, weeks, or months of training.

Send: Climbing a route cleanly in one attempt without falling or stopping to rest.

Strength-to-weight ratio: A ratio of measured force production to body mass of subject that allows the force production to be normalized across all body sizes.

Introduction

Climbing is a multifaceted sport. There are physiological, psychological, and anthropometric factors that play into an athlete's performance. In addition, there are complex interactions that constantly occur between the fingers and the climbing wall. The direct composition of factors that determine an athlete's performance varies, depending on the discipline of climbing they are engaged in. However, out of all the variables that account for the variance in performance, the most strongly correlated is the relative strength finger flexors.

Competitions in climbing have rapidly increased in popularity and prevalence in recent years. (Watts, 2004) This rise in popularity has resulted in a dramatic increase in climbing research. It has also catapulted climbing into the mainstream media. What was once a dirtbag sport where conquest was the primary goal and only the marginalized of society participated, has transformed into the highly accessible performance sport it is today. Due to this shift in what it means to be a climber, there has been increasingly more focus on how climbers can improve their performance.

Understanding how the fingers interact, not only as individual variables, but with each other is key to understanding how they interact when subjected to the stresses of climbing. Quaine, Vigouroux, Paclet, and Colloud (2011) examined a specific type of grip in climbing, the closed crimp, or full crimp, which is the the strongest grip in climbing. Expanding on this, Amca, Vigouroux, Aritan, and Berton (2012) conducted a study with the aim of furthering their understanding of how the most commonly used climbing grips and hold depths influenced finger force capacities. They found that there was significant difference between the vertical forces depending on the hold depth and grip technique used. The researchers theorized that this was not as influenced by internal biomechanical factors, as it was by finger-hold interactions. This demonstrated that future studies had to selectively choose the hold depth on which they conducted maximal strength tests to account for finger-hold interactions.

Another key technique for ensuring that strength is properly tested is to use a horizontal force plate and arm fixation while seated. Quaine, Vigouroux, and Martin (2003) studied the forces of each finger during different gripping positions. Another technique for ensuring that strength is properly tested, and one that more closely mimics climbing, is to use a hanging position. Morenas, del Campo, Román, Horrillo, and Navarro (2013) examined the mechanical load on the fingers in hanging positions.

Fanchini, Violette, Impellizzeri, and Maffiuletti (2013) conducted a study on climbing specific finger force. The subjects were evaluated based on their maximal voluntary contraction (MVC) and rate of force development (RFD) in a crimp and open-crimp hand positions. Fanchini et. al found boulderers to have a significantly greater MVC and RFD than sport climbers in both positions.

Magiera et al. (2013) and Watts (2004) both studied performance related factors in experienced sport climbers. Magiera et al. (2013) assessed their subjects based on 43 different variables and then categorized them into three main areas: physical, technical, and mental. Those categories explained the variance in performance 38%, 33%, and 25% respectively. Watts attempted to describe high-level climbing performance based on his analysis. He categorized the existing research into two different areas, the athletic profile of climbers and the activity model. Micholav (2014) worked to characterize the type of physical activity that is required for climbing and to design an effective training program. He deduced that through the many disciplines of climbing, the performance limiting factors and training methods are identical.

In addition to the physical determinants, specific anthropometric characteristics are thought to be a determinant of elite performance in many sports. Previous studies have indicated the climbers are small in stature, have low body mass and low body fat content, and have a high handgrip strength to body mass ratio. (Tomaszewski, Gajewski, & Lewandowska 2011; Ozimek, Rokowski, Draga, Ljakh, Ambroży, Krawczyk, et al. 2017) Despite all the pre-existing literature there is still much debate as to which physiological and anthropometric characteristics are the most important. Trainable components, however, account for most of the variance in ability.

Climbing performance is strongly correlated to relative finger flexor strength and understanding how the fingers interact with each other is critical to studying their interactions when climbing. The principle of superposition and the multiple synergies the brain must organize are some examples of the many complexities that need to be taken into consideration. For this reason, it is important to analyze the fingers in order to maximize the potential performance benefits. How finger force production is measured and reported on, however, must be carefully considered in order to increase the validity and reliability of the results. Taken as a whole, measuring the individual fingers in a climbing specific way and in accordance with previous studies would be of great value to the community.

This study attempted to undertake that task by examining individuals aged 18-54 with at least one year of climbing experience. Participation in this study required one session which consisted of anthropometric measurements (height, weight, and finger length), a questionnaire detailing their climbing experience, and maximal voluntary contraction (MVC) testing. For the MVC testing, three trials were performed by all fingers together in an open grip position, followed by three trials of each individual finger. The individual fingers were tested in a set with the order randomized by a computer random generator. Three minutes of rest was given between each trial of all four fingers, as well as, between each set of individual fingers. This was done to ensure sufficient recovery was given to the forearm musculature so that a proper MVC could be recorded.

There were two instruments used in this study, a questionnaire and a weight sensor. The questionnaire, along with the finger length measurements, were used to determine which factors accounted for the differences in relative contribution of each finger. The weight sensor was made by Entralpi. It assessed how much weight each participant was able to take off and that value was then used to determine the amount of force they were able to produce. The data was analyzed using various t-tests to determine significance.

Literature Review

Introduction

Climbing is a multifaceted sport. There are physiological, psychological, and anthropometric factors that play into an athlete's performance. There are also complex interactions that are constantly occurring between the fingers and the climbing wall. Of all the variables that account for the variance in performance, one of the most strongly correlated is the relative strength finger flexors (Michailov, Mladenov, & Schöffl 2009; Magiera et al. 2013; Schweizer & Furrer 2007).

Finger Forces

Understanding how the fingers interact, not only as individuals, but with each other is key to understanding how they interact when subjected to the stresses of climbing. Flanagan, Burstedt, & Johansson (1999) studied control of fingertip actions during three finger tasks, specifically the thumb and two fingers. They measured the force applied on the x, y, and z axis and the torques of each digit. There were eight adult subjects, five males and three females, who participated in this study. Flanagan et al. (1999) found that the normal forces produced by each digit increased linearly with the load. When the subjects initially picked up the object their grip force spiked and then dropped to a sustained level. It was determined that the subjects attempted to minimize the forces applied by each fingertip, but at the same time ensure that grasp stability was preserved. They also found that the subjects avoided applying horizontal forces, which would have contributed to a greater overall force production.

The redundancy problem—formulated by N.A. Bernstein in 1935—stated that there are an infinite number of combinations of muscle forces that can provide a given force output. He went on to explain that, “the main problem of control of voluntary movement [was] the elimination of redundant degrees of freedom.” (pg. 276) Li, Latash, and Zatsiorsky (1998) wanted to test the idea that motor synergies provide solutions to the motor synergy problem. The authors recorded forces produced in one, two, three, and four finger tasks. They measured the maximal voluntary contraction (MVC) of ten subjects, male and female, and found that individual finger forces were smaller in multi-finger MVC tasks than in single-finger MVC tasks. This deficit also increased as the number of fingers involved increased. This confirmed the idea that the central nervous system (CNS) has a limit to how many synergies it can support at one time. The CNS cannot maximally activate the muscles of all the fingers at the same time. Li et al. (1998) hypothesized that the force sharing pattern was organized in such a way that it would reduce unnecessary rotation. Their results suggested that there are at least two levels of control over motor tasks, a central neural drive level and a synergy level.

Motor Control

The synergy level of motor control, specifically how muscles (or fingers) compensate for the errors and variability of others, is an important field of study. Bugeon, Latash, and Zatsiorsky (2008) studied multi-digit coordination with finger addition and removal. They examined seven subjects. The subjects were instructed to hold a vertically oriented handle and then either add or remove the index or pinky finger. They found a significant increase in gripping force when either an antagonist was added ($p=0.006$) or an agonist was removed ($p=0.008$). This study further supported the idea that the central nervous system (CNS) is limited in its ability to simultaneously organize two or more levels of synergies. Evidence for a feed-forward control mechanism was observed with the addition and removal of fingers. This means the response from the CNS was controlled in a pre-determined manner without regards to how the load reacts.

Bugeon et al. (2008) explained the principle of superposition which stated that the net response caused by two or more stimuli is the sum of the responses that would have been caused by each stimulus individually. It was a vector quantity that applied to all linear systems. In the case of the fingers, the two stimuli were “grip harder” and “prevent tilting.” The existence of these two co-occurring stimuli was what accounted for the force deficit in previous studies. With the foundation of knowledge on how the brain organized the fingers and what lead to the force sharing patterns, it was possible to research the forces on the fingers that occurred while climbing.

Feed-forward systems are based upon previous knowledge about the process and require a great deal of coordination, both physically and mentally. Kjnoshita, Kawai, and Ikuta (2007) examined the contributions and coordination of external finger grip forces during prehension using three, four, and five fingers. Ten subjects lifted a force transducer grip apparatus. The authors continuously recorded the grip force while the subjects grasped three different object weights, 200g, 400g, and 800g. They also tested the grip force with two different surface structures on the object, plastic and sandpaper. They found that variations in the object’s weight and surface friction altered the total grip force the subject was produced. Throughout the testing, the largest changes were observed in the index finger, followed by the middle, ring, and pinky. The percentage contributions for each finger during the five finger tests were 42.0%, 27.4%, 17.6%, and 12.9% for the index, middle, ring, and pinky finger, respectively.

Kjnoshita et al. (2007) found these values to be consistent for all object weights and surfaces. These findings suggested that a common scaling factor was used by the brain for objects weighing 800 grams or less. The percentage contributions during the four finger tests were 42.7%, 32.5%, and 24.7% for the index, middle, and ring finger, respectively. During the three finger tests, the percentage contributions were 43.0% for the index finger and 56.9% for the middle. These findings demonstrated that the force contribution of the index finger remained largely unchanged during the different grip modes, which agreed with the notion that digit force adjustments are controlled in a feed-forward way. Higher surface friction was also found to result in a faster lifting initiation and required less grip force to move. The results of this study however, cannot be directly compared to the forces exerted during rock climbing because of the different methods of force application. In rock climbing, the forces are applied in a vertical direction with the hand superior to the elbow. However, in this study the forces are measured in a horizontal direction with the hand and elbow at equal heights.

Previously, digit force sharing research had only been approached in noncliming specifc methodologies, which is characteristic of measurements taken in the anteroposterior direction or with the thumb opposing the four fingers. Quaine, Vigouroux, Paclet, and Colloud (2011) examined one specific type of grip in climbing, the closed crimp, also known as the full crimp. The strongest grip in climbing was the closed crimp grip. This was due to the way the thumb was positioned, on top of the index finger, acting as an additional force assisting the other four fingers. The aim of this study was to examine how the addition of the thumb modified the force exerted by the other four fingers. Nine male climbers participated in this study. They were seated while performing the force testing which does not closely mimic the way in force is applied in climbing. The results demonstrated a significant difference ($p = 0.02$) between the forces applied in the grip without the thumb and the grip with the thumb. The thumb increased the total force exerted by the hand. Due to the fact that the contribution of the other fingers decreased with the addition of the thumb, the authors theorized this indicated that the brain re-organized the force sharing among the fingers.

Digit Force Contributions

Research examining the digit force contributions in the anteroposterior direction, while not climbing specific, help to shed light on the mechanisms of synergistic control. MacDermid, Lee, Richards, and Roth (2004) measured the contribution of each finger to the overall grip strength. The apparatus that they used, tested the fingers stacked vertically while they squeezed against the palm. The subjects—35 men and women— had no history of upper extremity injury. They were tested while performing sets of three maximal effort attempts on two separate occasions. The percentage contributions of the index, middle, ring, and pinky finger were 25%, 35%, 25%, and 15%, respectively. This study also demonstrated that the ulnar side of the hand accounted for 40% of the overall grip strength, whereas, the radial side accounted for 60%. Various anthropometric measures, such as, body size and finger length, were moderately correlated to strength.

Not only does the position of the fingers influence the force production, but the wrist plays a major role as well. Li (2002) examined the influence of wrist position on individual finger forces. Nine subjects performed a maximal voluntary contraction while moving the wrist through its range of motion. A specialized device measured individual finger forces, wrist flexion/extension, and radial/ulnar deviation. The author found that wrist position had a significant effect on total force production of the hand and individual finger force production. Peak forces were at 20 degrees of wrist extension and five degrees of ulnar deviation. The percentage contributions of each finger were 32.2%, 32.6%, 23.5%, and 11.7% for the index, middle, ring, and pinky, respectively. The further the wrist moved from the optimal position described above, the forces produced by each finger decreased, although not proportionally.

Finger Fatigue

In addition to the body segment and joint position, fatigue influences force production of the hand. Danion, Latash, Li, and Zatsiorsky (2000) investigated the effects of fatigue on multi-finger coordination. The authors had fourteen subjects, both male and female, perform maximal isometric contractions with all four fingers for 60 seconds. They measured the finger forces during single and multi-finger bouts and at two force application sites, from the distal phalange and from the proximal phalange. Danion et al. (2000) found that for four finger tasks, force declined approximately 43% at the application site involved in the fatiguing exercise, but only by approximately 23% at the other site. For single finger tasks, force dropped about 25% in every finger following a fatiguing exercise. They also found that when force was produced by one finger it resulted in an involuntary force production by other fingers. There was a force deficit that exists among the fingers. This means that the total maximal voluntary contraction of all four fingers was smaller than the sum of all the fingers individually, and it increased with fatigue. However, force sharing patterns were not altered with fatigue. These results demonstrated that fatigue is not limited to the capabilities of muscles to generate force, suggestive of a neurological component that is affected with time.

Lifting Forces In Rock Climbing

Bourne, Halaki, Vanwanseele, and Clarke (2011) investigated the shallow edge lifting force in skilled rock climbers. They were testing the relationship between fingertip soft tissue anatomy and strength to weight ratio to the lifting forces. In all, fifteen subjects participated in the study, eleven males and four females. The subjects performed single hand hangs on edges of depth 2.8, 4.3, 5.8, 7.3, and 12.5 mm. They were standing on a force platform, with one of their hands hanging on the variable edge. This apparatus measured the weight taken off via the hand which could then be used to make inferences as to how much force they were exerting. Fingertip soft tissue dimensions were assessed via ultrasound. The authors found that the forces that the climbers were able to exert on the two smallest and largest edge sizes were uncorrelated with each other ($r < 0.1$). There was a moderately strong ($r = 0.65$) correlation between the force exerted on the 2.6 mm edge and the tip of bone to tip of finger pulp measurement. A weak positive relationship ($r < 0.37$) also existed between the tip of bone to tip of finger pulp measurement and the larger edge sizes. This relationship suggested that the increased deformation of the fingers in climbers with more fingertip pulp allowed for more skin contact area on the rock which helped increase the force production. The study also demonstrated that maximum force on a large edge does not predict maximum force on shallow edge.

Amca, Vigouroux, Aritan, and Berton (2012) conducted a study with the aim of understanding how the most commonly used climbing grips and hold depths influenced finger force capacities. The subjects—ten advanced male climbers—performed maximal voluntary force hangs on four different hold depths, ranging from 1-4 cm. They used the slope, half-crimp, and full crimp grips and performed the contractions in two different directions, anteroposterior and vertical. They used a highly specialized device that could sense force with six degrees of freedom. They found that there was significant difference ($p < 0.05$) between the vertical forces depending on the hold depth and grip technique used. The resultant forces in the vertical direction ranged from 350.8 N (1 cm hold) to 575.7 N (4 cm hold). The authors theorized that this was not as influenced by internal biomechanical factors, as it was by finger-hold interactions. The forces applied in the anteroposterior direction were also found to be statistically different from one another, but they were lower than the vertical, ranging from 69.9 N to 138.0 N. The authors noted that the forearm position during the testing of the vertical forces more closely mimicked actual climbing technique because in that position the hand and wrist were superior to the elbow. The large variation in force production between the different edge sizes demonstrated that future studies had to selectively choose their test hold size while performing maximal strength tests to account for finger-hold interactions.

Strength Testing

One technique to ensure that the strength of the forearm is properly tested is to use a horizontal force plate and arm fixation while the subject remains seated. Quaine, Vigouroux, and Martin (2003) studied the forces of each finger during different gripping positions. They had six elite male climbers apply fingertip forces to horizontal force plates while sitting down. Quaine et al. (2003) found the middle finger to apply the greatest force no matter the position. The authors also found the relative involvement of the ring finger to be 105% in the sloped posture compared to the reference position which had the fingers apply force while in an anatomical position.

Another technique for ensuring that strength is properly tested, and one that more closely mimics climbing, is to use a hanging position. Morenas, del Campo, Román, Horrillo, and Navarro (2013) examined the mechanical load on the fingers in hanging positions. Sixty-four male climbers participated as subjects in this study. The authors tested the climbers in three different positions, crimp, half-crimp, and slope. They found that the ring finger has the highest mechanical load in the half-crimp position, middle in slope, and index in crimp (because thumb is placed over the index). They also concluded that these findings are relevant to climbers of all levels of ability. While it is necessary to assess the force produced by the individual fingers, it is also important to evaluate the strength of the associated actions of the wrist.

Schweizer and Furrer (2007) did a study attempting to correlate forearm strength and sport climbing performance. The authors tested 25 recreational climbers while they performed three different movements of the forearm; wrist flexion, proximal interphalangeal joint (PIP) flexion of the middle and ring fingers, and a rolling movement with all fingers involving the distal interphalangeal, proximal interphalangeal, and metacarpal interphalangeal joints. They concluded there was no correlation between absolute maximum strength and performance (r=0.262, r=0.093, r=0.133 respectively). There was moderately strong correlation between relative strength of all three exercises and performance, with concentric wrist flexion being the best predictor (r=0.57).

Philippe, Wegst, Müller, Raschner, and Burschen (2012) examined climbing specific finger power. They studied 12 elite climbers and 12 non-climbers. They found maximal voluntary contraction and strength-to-weight ratio to be greater in climbers than non-climbers and greater in men than women. Re-oxygenation of the forearm muscles was faster in climbers than in non-climbers, regardless of sex. Strong correlations between on-sight performance and strength-to-weight ratio were only seen in females. This research was one of the first studies to demonstrate the relationship for female climbers, as previous studies only included males. Philippe et al. (2012) went on to propose that because this study confirmed that male and female specific forearm physiology were homologous and they had nearly identical performance limiting factors, men and women could engage in similar training programs.

Determinants of Performance

Specific anthropometric characteristics were thought to be a determinant of elite performance in many sports. Previous studies indicated the climbers are small in stature, have low body mass and low body fat content, and have a high handgrip strength to body mass ratio. Despite all the pre-existing literature there was still much debate as to which physiological and anthropometric characteristics were the most important. Tomaszewski, Gajewski, and Lewandowska (2011) measured 21 male lead climbers and compared them to a control group of 165 sedentary university students. For the arm measurements, the climbers were found to have a significantly larger arm and forearm circumference, as well as, a longer arm length and span. They were also found to have a significantly smaller pelvis and knee width.

In addition, the authors compared the two groups against a number of different indexes. The climbers were found to have a greater arm circle index, arm index (ratio of arm length to body height), ape index (ratio of arm span to body height), and manouvrier's index (ratio of leg length to sitting height). The climbers also had a significantly smaller pelvis to shoulder width ratio which is indicative of a more triangular torso. Within the group of climbers, self-reported ability was found to be correlated ($r = -0.614$) with body fat percentage.

This study contradicted previous studies. Tomaszewski et al. (2011) determined there was no significant difference between body mass index or body fat percentage in the climbers and control group. A major limitation of this study was apparent in the fact that the authors did not only study elite climbers. They tested climbers of a large range of ability. These results indicated that climbing performance is not solely related to anthropometric variables, but was a complex mix of anthropometric, physiological, and psychological characteristics.

Michailov, Mladenov, and Schöffl (2009) examined a variety of anthropometric factors of elite boulderers. They tested 25 boulderers at the 2007 World Cup in Sofia. The authors measured the climbers for height, body mass, BMI, body fat percentage, muscle mass percentage, and grip strength. Michailov et al. (2009) also administered a sport-specific strength test. For the anthropometric variables, they found little correlation ($r = -0.2$) between body fat percentage and performance, however, there was a moderately strong correlation ($r = -0.52$) between weight and performance. Regarding trainable variables, there was a strong correlation ($r=0.947$) between strength endurance and performance and a moderately strong correlation ($r=0.666$) between relative strength and performance. The authors theorized that this information could be used to help design the most effective training programs.

Ozimek et al. (2017) examined twenty climbers and placed them into two different groups based on their ability level, elite or advanced. They attempted to determine the primary somatic and motor determinants for elite climbers. The only statistically significant difference ($p = 0.003$) in anthropometric characteristics between the two groups was found to be in calf circumference. The elite climber’s calves were significantly smaller. The authors found a greater number of significantly different motor characteristics. This provided further evidence to the fact that trainable, physiological factors accounted for a greater amount of the variability among climbers. The only important anthropometric factors that were identified were low body mass, low fat composition, and slender body build.

Fanchini, Violette, Impellizzeri, and Maffiuletti (2013) conducted a study on climbing specific finger force. They studied elite climbers (bouldering and sport) and non-climbers. The subjects were evaluated based on their maximal voluntary contraction (MVC) and rate of force development (RFD) in a crimp and open-crimp hand positions. Fanchini et al. (2013) found climbers to be stronger than non-climbers and boulderers to have a significantly greater MVC and RFD than sport climbers in both positions.

Macdonald and Callender (2011) described the athletic profile of highly accomplished boulderers. They studied 12 male climbers who were matched for age, height, and body mass to 12 non-climbing aerobically trained counterparts. They looked at body composition, handgrip and climbing specific finger strength, and shoulder girdle and abdominal muscle endurance. The authors found body composition, handgrip endurance, and abdominal endurance to be similar, except for the bone mineral density of climber’s forearms, which was found to be greater. Handgrip and climbing specific finger strength were greater in climbers than non-climbers. Shoulder girdle endurance was also far greater in the boulderers than in the aerobically trained non-climbers.

Variance in Rock Climbing Performance

Magiera et al. (2013) studied performance related factors in experienced sport climbers. Thirty experienced climbers with an average red-point of 5.13b (Yosemite Decimal System) were tested. The authors assessed them based on 43 different variables, which included measures of physical fitness, coordination, aerobic power, anaerobic power, mental characteristics, technical skills, and tactical skills. These characteristics were categorized into three main areas: physical, technical, and mental. They explained the variance in performance 38, 33, and 25% respectively. While on-sight and red-point competition formats have different performance requirements, seven variables, (maximal relative strength of the fingers, mental endurance, climbing technique, isometric endurance of the fingers, number of errors in reaction time test, ape index, and O_2 uptake during arm work at anaerobic threshold) explained 77% of the requirements common to both.

Mermier, Janot, Parker, and Swan (2000) sought to identify physiological and anthropometric determinants of climbing performance in recreational climbers. The authors recruited 44 subjects from the University of New Mexico, excluding those without climbing experience. The subjects all climbed two separate routes to assess their performance. Mermier et al. (2000) assessed the participants for various anthropometric, physiological, and demographic variables. They concluded that trainable components explained 58.9% of total variance in performance, while the untrainable components, anthropometry and flexibility, only accounted for 0.3% and 1.8% respectively.

Characterization of Rock Climbing

Watts (2004) surveyed existing research on the physiology of climbing and then described high-level climbing performance based on his analysis. He focused on studies that looked at performances of at least 5.11 difficulty (Yosemite Decimal System). Watts (2004) categorized the existing research into two different areas, the athletic profile of climbers and the activity model. He further subdivided the athletic profile area into anthropometry (height, mass, BMI, etc), muscular strength and endurance (strength:weight ratio, absolute strength, etc), flexibility (ROM in hip and shoulders), and aerobic power (VO_{2max}).

Activity analysis was divided into the subcategories of oxygen uptake and energy expenditure (climbing specific VO_2, HR, etc), blood lactate (increases due to climbing), muscular strength and endurance (RFD vs. absolute strength), and neuromuscular recruitment (forearm EMGs). He found that climbers are typically shorter in height with lower body mass and body fat percentage. In terms of muscular strength and endurance, strength to weight ratio was of great importance and was far greater than what was observed in an untrained population. Aerobic power, flexibility, and anthropometric metrics were not overly impressive, however, they were still above average.

Micholav (2014) characterized the type physical activity that is required for climbing and for an effective training program. He deduced that through the many disciplines of climbing, the performance limiting factors and training methods were identical. The levels and proportions of development of the various abilities were different. Micholav (2014) concluded that the demands of climbing were unique in that over one-third of the time was spent in a state of isometric contraction. This caused the heart rate to rise disproportionally to oxygen consumption and disallowed heart rate from being used as a training guidance. He found the main goals of training to be sport-specific strength and strength endurance of the forearm flexors, explosive strength of the arm flexors, strength endurance of the shoulder girdle, and core maximal strength.

Conditions for Research On Rock Climbing

Michailov et al. (2018) assessed the reliability and validity of arm fixation during climbing-specific finger-strength measurements. They also investigated the the reliability of finger-strength tests and the relationship between maximal finger flexor tests and climbing ability. Michailov et al. (2018) tested two groups of male climbers. Both groups performed maximal strength tests with and without arm fixation, however, the first group was better at bouldering and the second group was better at sport climbing. Arm fixation was found to lead to lower scores on both the maximal finger strength and maximal tests. After calculations, normalized maximum finger strength was more closely related to bouldering ($r = 0.815$) and sport climbing ability (r = 0.690) when no arm fixation was used than when it was used (r = 0.649 for bouldering and r = 0.648 for sport climbing). Interestingly, Michailov et al. (2018) found the maximal strength test with arm fixation to have the highest intra-class correlation coefficient (ICC), which is a measure of test-retest reliability. Nevertheless, testing without arm fixation is more climbing specific and, therefore, more applicable to the climbing population.

Draper et al. (2011) saw that much of the development and data collection on rock climbing of the last few decades has been, to a certain degree, haphazard. The authors of this study recommended a standardized method of reporting characteristics of subjects, developed classification tables for males and females based on ability levels, and suggested a new comparison grading scale.

According to Draper et al. (2011) the core characteristics that should be included in the paper were basic biographical data (age, height, mass, body fat percentage, and aerobic capacity), climbing specific factors (climbing ability, years of climbing experience, days/hours of training per week, and the main disciplines of the subjects), and the testing environment (venue, nature of the protection, and how much knowledge/practice on the route the climbers had). The authors adapted a previously existing classification table after consulting with over 40 experts in the field of climbing. The divisions in the table correspond with natural breaks in climber ability level, as much as possible. Draper et al. (2011) also recommended that either the Watts or Ewbank scale. The first was the original researcher based system and the second was a whole number based grading scale.

Summary

Climbing performance was strongly correlated to relative finger flexor strength and understanding how the fingers interact with each other was critical to studying their interactions when climbing. The principle of superposition and the multiple synergies the brain must organize were some examples of the many complexities that need to be taken into consideration. For this reason, it was important to analyze the fingers in order to maximize the potential performance benefits. How finger force production was analyzed and reported on, however, must be carefully considered in order to increase the validity and reliability of the results. Taken as a whole, measuring the individual fingers in a climbing specific way and in accordance with previous studies would be of great value to the community.

Methods

Introduction

The purpose of this study is to evaluate the contribution of individual finger force production to open hand grip force production in climbers aged 18-54. As climbing increases in popularity, the need to understand how each of the fingers contribute to the overall force production increases. This is an understudied topic area. There are studies that examine all the fingers at the same time, but few that examine them individually, and even fewer that attempt to examine why there are variances in their respective contributions. This study examined these variances and the potential reasons for their differences. Testing included a questionnaire followed by one session on a hang board.

Population

This study examined individuals aged 18-54 who had at least one year of climbing experience. An additional criterion was absence of injury to any portion of their upper extremities for at least six months prior to testing. The major recruitment site was at Vertical World Seattle with in-person invitations and email sign-ups. All of the participants were members, staff, or other paying customers of Vertical World. This helped to ensure that the participants would be familiar with climbing and the jargon involved. The patrons of Vertical World offer a wide range of participants to be selected, ranging from beginner to elite climbers. Diversity among the ages adds validity to the study because individuals can continue to climb at a high level well into their lives. Beginner climbers were excluded from this study because of the increased injury risk that exists with them, they are not used to the feeling of pulling with all of their strength.

Research Procedure

Participation in this study required one meeting time. At the beginning of the session the principal investigator (PI) handed out a Physical Activity Readiness Questionnaire (PARQ) (Appendix D) and Informed Consent (Appendix E) for the participants. Both of these forms needed to be signed in the presence of the PI. After completion of those two forms the participants then had to fill out a questionnaire detailing their climbing experience. There was a question on this form about injuries that could lead to exclusion from the study. Once the forms were all completed and valid participation was confirmed the PI took various anthropometric measures, including finger lengths, height, and weight.

The participants were then instructed to engage in a general warm-up consisting of five minutes on a stationary bike and ending with four to ten scapula pull-ups depending on their self-perceived ability level. A climbing specific warm-up, which consisted of 15 minutes of climbing, beginning with low intensity movement and ending with high intensity movement, followed immediately after the general warm-up. After the climbing warm-up period, the participants were then led to the area where testing was completed. They were given one minute to familiarize themselves with the device and hang board before beginning a series of hangs. All of the hangs were done only with their dominant hand. The first series of hangs they performed were seven seconds in length with one minute of rest in-between and were done on a 20mm edge (See table 1).

Table 1
Warm-Up Protocol

Hang Number	Hang Time (s)	Hang Intensity
1	5	5/10
2	5	6/10
3	5	7/10
4	5	8/10
5	5	9/10

Following the conclusion of the warm-up, the four finger grip was the first to be tested. That grip position was tested three times with three minutes of rest given in-between each trial. The order in which the fingers on each hand were tested were randomized by a computer random generator. Once testing of the fingers began, each finger was tested successively, one after the other until all four had been tested. A total of three minutes of rest was given between the three sets of measurements of the fingers. At the conclusion of the testing, the participants were given an opportunity to ask questions and review their results before the cessation of the session.

Instruments

A questionnaire was used in this study to determine which factors account for the differences in the relative contribution of each of the fingers. They assessed the following factors, dominant hand, strongest finger, preferred hold type, least preferred hold type, main discipline, highest red-point (top-rope, boulder, and sport), climbing age, training age, and injury history.

There were two devices used to assess the finger strength of the participants, Tindeq V-rings and Progressor and a sensor from Entralpi. The Tindeq devices were used to assess single finger strength and the Entralpi sensor was used to assess the four finger strength.

Data Collection

Before any testing began, each participant filled out a PAR-Q and the Informed Consent form. The PAR-Q ensured that each participant was physically eligible for participation, and the Informed Consent form provided information regarded what a participant would be involved in. Additionally, participants also filled out the questionnaire which further ensured that they would be physically eligible, as well as detailing their past experience. After completion of the three forms, the testing portion of the session began. The data was recorded in the data collection sheets. The PI collected the questionnaire and data collection sheets at the conclusion of the session. The data was then transcribed in an Excel sheet. Once the participant finished all the data collection, participation was considered finished.

Data Analysis

The data collected from the assessments were analyzed as a part of the cross-sectional analysis of this study. The answers from the questionnaire were analyzed with a t-test to each of the finger's max strength, as well as, the four-finger maximum force production. Then the relative contributions for each of the four fingers was also analyzed with a t-test to the answers from the questionnaire. An alpha value of 0.05 was set to determine significant difference.

Confidentiality

Each participants name was de-identified with assigned numbers from a four-digit random number generator. Only the PI had access to other required personal information, for research related purposes. Data was stored securely and anonymously on a password protected laptop and was not shared with anyone. During the sessions other people may have been able to watch, but the results were not discussed or disclosed to anyone but the participant. Any data obtained from this study would be destroyed after three years.

Risks and Benefits

The risks involved with this study were minimal because there were no intense intervention and it was not invasive. However, there are inherent risks when using a hang board, as is the case when loading any finger to the maximum. The potential risk could be finger injuries as a result of the testing. In order to mitigate this the participants were subjected to a through warm-up and directed to communicate any pain felt during the course of testing. If the participant ever felt uncomfortable with any aspect of the testing they were free to withdraw from the study at any time without consequences.

The sole direct benefit for each participant was the knowledge of the maximum strength of each of their fingers, as well as, their maximum open hand strength. The potential benefit to society as a whole is the improved knowledge about the various factors that account for the variance in climbing specific strength.

Results

Characteristics of the Subjects

The characteristics of the study participants were shown in table 2. This study consisted of 21 climbers (14 male and 7 female). The primary discipline that this group practiced was bouldering (n=11), followed by sport (n=8), and lastly top-roping (n=2). A slight majority had no history of finger injury (n=11), while the other 10 did have a history of injury. In regards to the dominant hand of the participants, 15 of the subjects were right hand dominant and six were left hand dominant.

Males were significantly older than females ($p = 0.032$). They also had a significant larger body mass ($p = 0.029$) and were taller ($p = 0.002$). Although, the difference in mean body mass index was of no significance. There was no significant difference found between the two sexes in respect to the lengths of the index and pinky fingers, however, the middle and ring fingers of males were found to be significantly longer ($p = 0.014$, $p = 0.018$).

The experience levels of the study participants were shown in table 3. No significant difference was found between the mean time the males and females had been actively climbing or in the amount of days they climbed per month. In regards to their ability, a significant difference was found between males and females in all categories, except for their highest VW sport red-point.

Table 2
Characteristics of study participants

	Total (n=21)	Male (n=14)	Female (n=7)	Significance
Age (years)	24.95 ± 5.60	26.36 ± 6.42	22.14 ± 1.21	0.032
Height (cm)	175.28 ± 8.19	179.05 ± 6.23	167.74 ± 6.35	0.002
Body mass (kg)	70.89 ± 9.17	74.13 ± 7.78	64.40 ± 8.68	0.029
Body mass index (kg/m2)	23.01 ± 1.95	23.12 ± 2.07	22.80 ± 1.82	NS
Index finger (cm)	8.94 ± 0.66	9.11 ± 0.58	8.60 ± 0.72	NS
Middle finger (cm)	9.93 ± 0.69	10.19 ± 0.59	9.42 ± 0.58	0.014
Ring finger (cm)	9.45 ± 0.75	9.71 ± 0.68	8.91 ± 0.62	0.018
Pinky finger (cm)	7.43 ± 0.51	7.53 ± 0.50	7.22 ± 0.47	NS

Table 3
Climber’s experience and abilities

	Total (n=21)	Male (n=14)	Female (n=7)	Significance
Experience (years)	5.08 ± 2.94	5.31 ± 3.57	4.64 ± 1.25	NS
Highest VW red-point boulder (IRCRA scale)	20.93 ± 2.12	21.68 ± 1.97	19.43 ± 1.64	0.015
Highest OD red-point boulder (IRCRA scale)	19.89 ± 2.90	20.92 ± 3.12	18.14 ± 1.31	0.016
Highest VW red-point sport (IRCRA scale)	15.91 ± 3.12	16.41 ± 3.26	14.80 ± 2.77	NS
Highest OD red-point sport (IRCRA scale)	16.36 ± 3.02	17.41 ± 3.23	14.71 ± 1.80	0.038
Total climbing days per month	15.38 ± 7.25	14.54 ± 6.94	17.07 ± 8.11	NS
Total climbing days at VW per month	11.90 ± 5.91	11.21 ± 5.70	13.29 ± 6.55	NS
Total climbing days OD per month	3.48 ± 2.99	3.32 ± 3.20	3.79 ± 2.74	NS

Notes. VW = Vertical World climbing gym, OD = Outdoors, IRCRA = International Rock Climbing Research Association

Digit Force Contributions

Table 4 shows the illustrates the digit force contributions among the fingers. The relative finger contributions among the participants remained constant in all but three of the comparisons that were made. There were only significant differences found between three groups, advanced and intermediate sport climbers at VW (figure 1), whether or not they had a history of finger injuries (figure 2), and based on the average length of the fingers for males (figure 3).

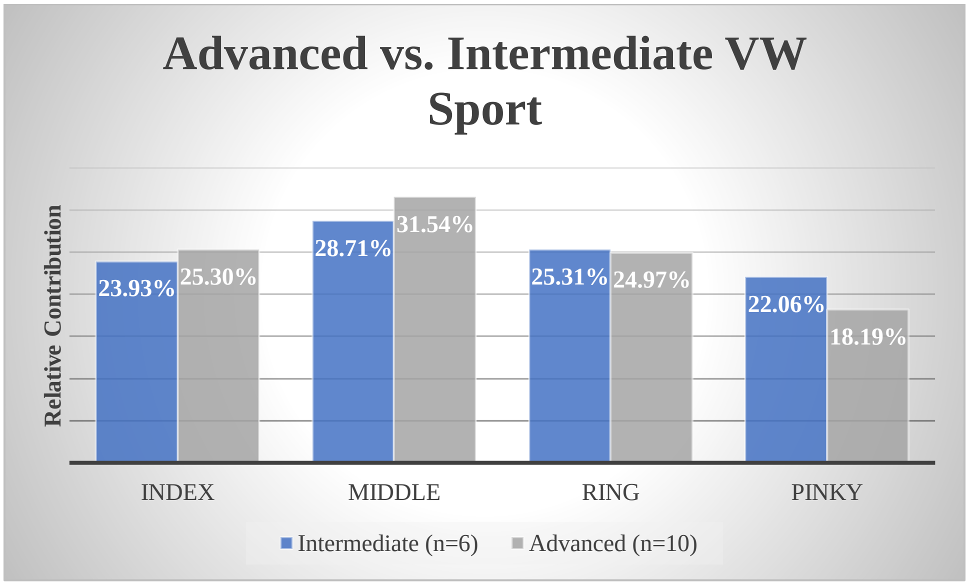

Figure 1

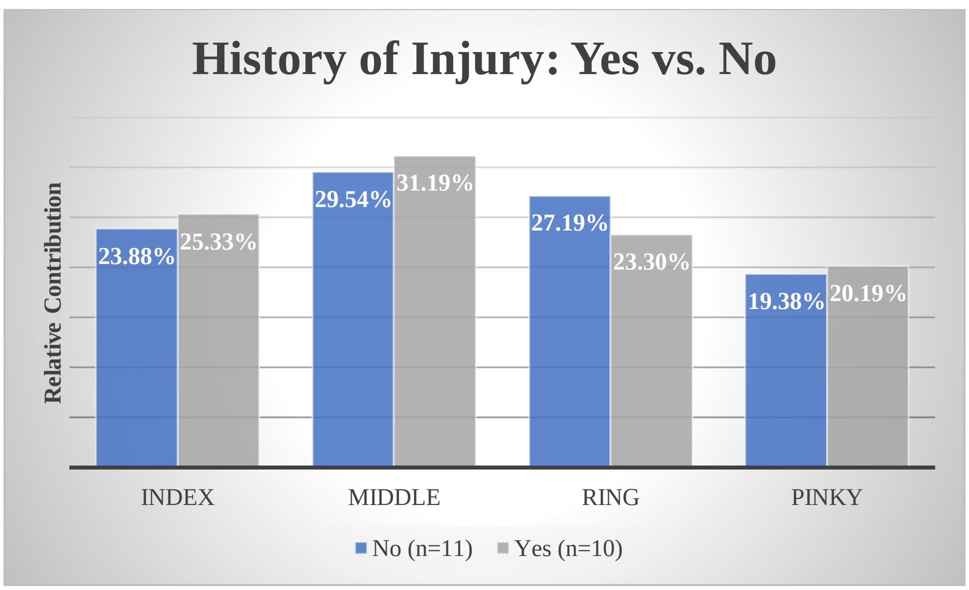

Figure 2

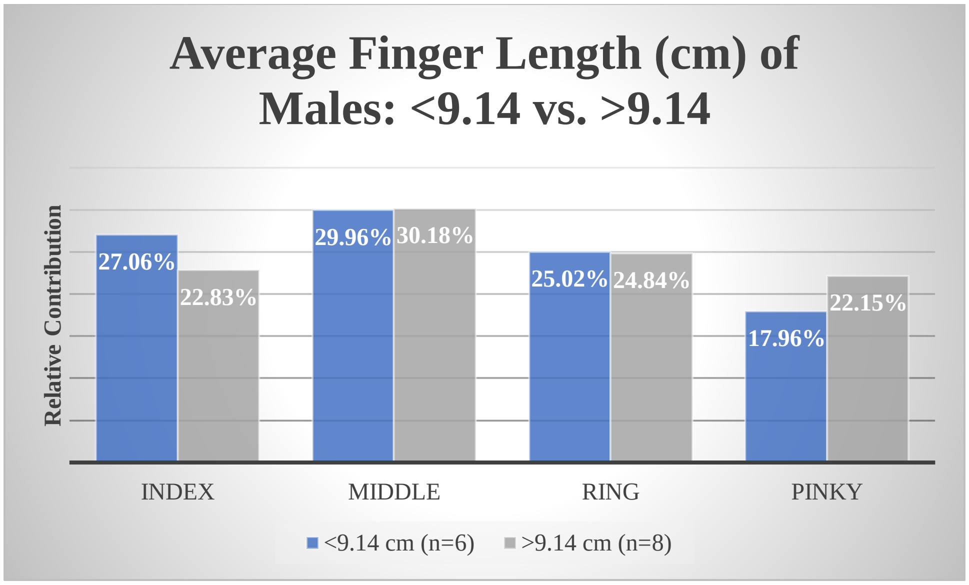

Figure 3

Between advanced and intermediate VW sport climbers there was a significant difference found in the middle and pinky fingers (p = 0.024, p = 0.039). The advanced climber's middle fingers contributed 2.83% more, while the intermediate climber's pinkies contributed 3.87% more. In those who had never suffered from a finger injury, their ring finger contributed 3.89% more to the overall force production than in those who had had one (p = 0.004). There were two fingers that exhibited significant difference when the average finger length of males was compared. Those were the index and pinky. In the male participants with an average finger length of less than 9.14 cm, their index finger contributed 4.23% more (p = 0.007). The male participants who had an average finger length greater than 9.14 cm received 4.19% of the force production from their pinkies (p = 0.006).

Table 4
Digit force contributions

	Min (%)	Max (%)	Mean (%)	SD (%)
Index	17.28	29.02	24.57	3.37
Middle	25.58	35.15	30.33	2.53
Ring	17.27	31.50	25.34	3.25
Pinky	14.29	27.88	19.76	3.10

Finger Length and Force Production

There were correlations found between proportion of body weight taken off and proportion of body length for two fingers, the index and pinky. As seen in Figure 4, there was a parabolic relationship between the aforementioned variables in the index finger of level 3 (advanced) climbers. The correlation coefficient was 0.418. The peak of the parabola was at a finger length of 5.08% of a subject's body height and the highest recorded value for proportion of body weight taken off was 27.44%.

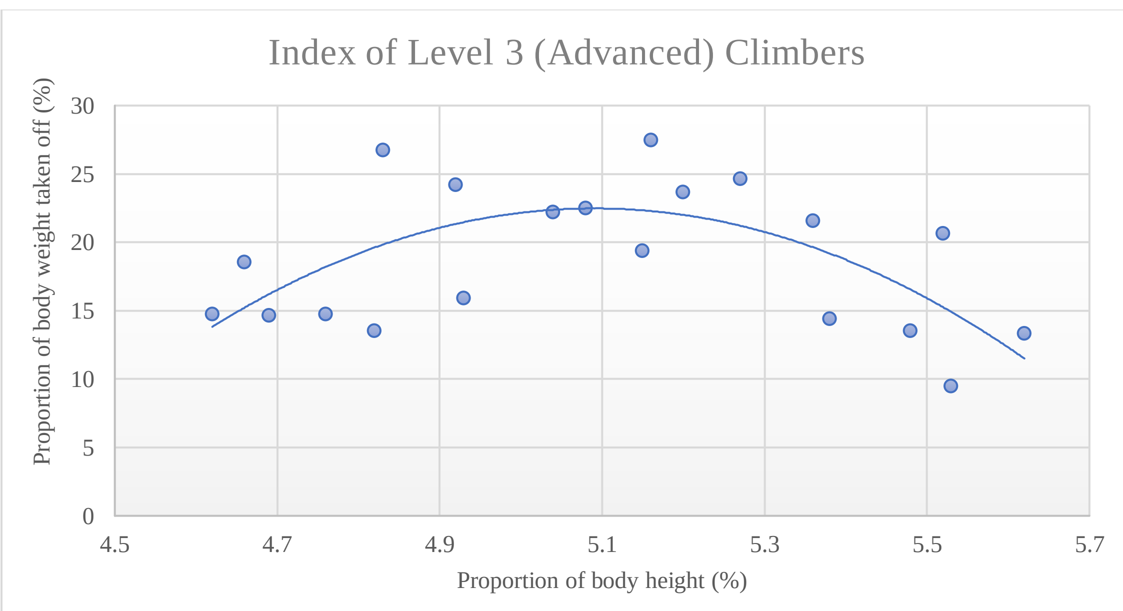

Figure 4

Additionally, the proportion of body weight taken off and proportion of body length for the pinky in level 3 (advanced) climbers was found to be parabolically correlated, with an r-squared value of 0.359. The peak of the parabola was found to be a 4.26% of a subject's body height, with the highest recorded proportion of weight taken off being 25.27%. This relationship is shown in figure 5.

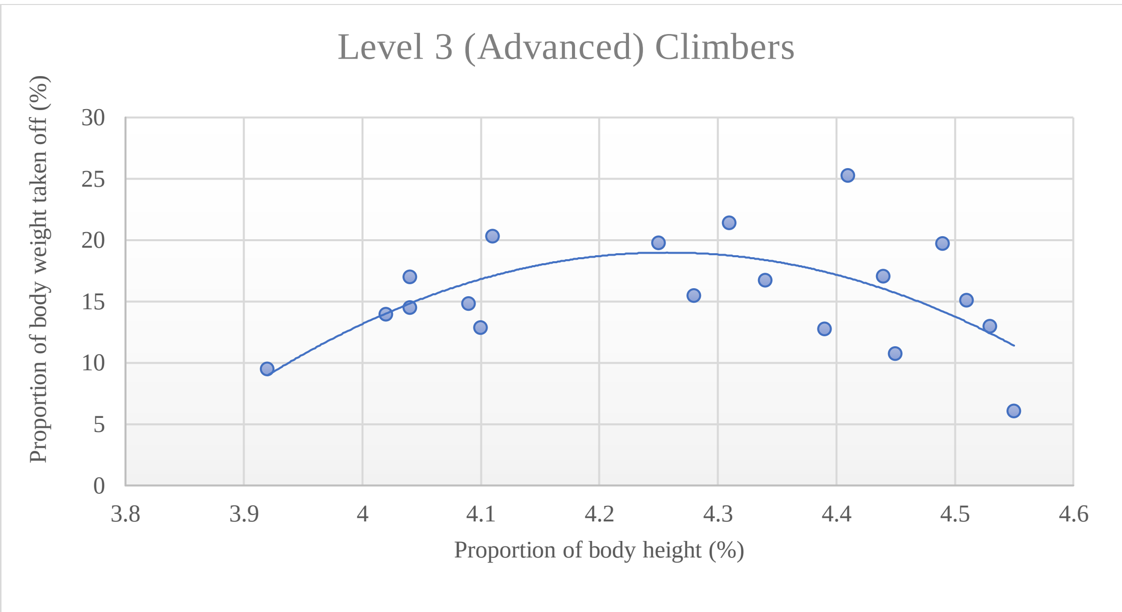

Figure 5

There was no relationship demonstrated for the middle (r^2 = 0.008) and ring fingers (r^2 = 0.018). However, the maximum proportion of their body weight that a subject was able to take off was found to be 32.55% for their middle finger and 30.32% for their ring finger.

Table 5 displays the percentage lengths for each of the four individual fingers. There was no significant difference found between those values in males and females, or between climbers of varied ability levels.

Table 5
Finger length

	Total (n=21)	Male (n=14)	Female (n=7)	Significance
Index (%)	5.10 ± 0.31	5.09 ± 0.28	5.12 ± 0.38	NS
Middle (%)	5.66 ± 0.24	5.69 ± 0.23	5.61 ± 0.26	NS
Ring (%)	5.39 ± 0.31	5.42 ± 0.28	5.32 ± 0.36	NS
Pinky (%)	4.24 ± 0.23	4.21 ± 0.24	4.30 ± 0.23	NS

Note. Length values reflected as a percentage of total body height

Relative Strength of the Fingers

In a comparison of level 3 (advanced) and level 4 (elite) boulderers, the relative strength of the full hand grip was found to significantly greater in the elite group. Table 6 summarizes the relative strength of each of the individual fingers. None of the individual fingers were found to be significantly stronger in elite versus advanced boulderers. In addition, body mass was not found to be significantly different between the two groups ($p = 0.241$).

Looking at level 2 (intermediate) and level 3 (advanced) sport climbers lead to significant difference being found in only the relative strength of the index finger ($p = 0.035$). Measurements in all other fingers, as well as in the full open hand grip, yielded no significant difference. Table 7 presented the recorded values for these climbers. Body mass, however, was found to be significantly less in advanced sport climbers.

The differences between males and females were presented in table 8. There was no significant difference found in the relative strength of any of the four fingers or in the full open hand grip. In terms of absolute strength, there was significant difference found in all but the ring finger ($p < 0.050$). The body mass of males was also greater than that of females ($p = 0.029$).

Table 6
Relative strength for boulderers

	Advanced (n=17)	Elite (n=4)	Significance
Hand (%)	54.45 ± 10.99	75.82 ± 9.34	0.010
Index (%)	17.88 ± 5.01	22.58 ± 3.56	NS
Middle (%)	22.33 ± 6.10	27.91 ± 5.53	NS
Ring (%)	19.43 ± 6.18	21.31 ± 7.84	NS
Pinky (%)	14.75 ± 4.81	17.24 ± 2.25	NS

Note. Values reflected as a percentage of total body weight taken off

Table 7
Relative strength for sport climbers

	Intermediate (n=6)	Advanced (n=10)	Significance
Hand (%)	52.74 ± 10.40	62.18 ± 15.21	NS
Index (%)	15.60 ± 3.07	20.57 ± 5.45	0.035
Middle (%)	19.50 ± 6.44	25.58 ± 6.20	NS
Ring (%)	16.99 ± 4.83	20.72 ± 6.65	NS
Pinky (%)	15.13 ± 6.11	14.96 ± 4.58	NS

Note. Values reflected as a percentage of total body weight taken off

Table 8
Relative strength for males and female

	Total (n=21)	Male (n=14)	Female (n=7)	Significance
Hand (%)	58.52 ± 13.55	61.94 ± 13.17	51.69 ± 12.44	NS
Index (%)	18.78 ± 5.06	19.72 ± 4.25	16.88 ± 6.31	NS
Middle (%)	23.39 ± 6.27	24.33 ± 5.40	21.52 ± 7.86	NS
Ring (%)	19.79 ± 6.35	20.38 ± 6.04	18.61 ± 7.28	NS
Pinky (%)	15.23 ± 4.51	16.37 ± 4.13	12.94 ± 4.65	NS

Note. Values reflected as a percentage of total body weight taken off

Discussion

The purpose of this study was to evaluate the contribution of individual finger force production to open hand grip force production in climbers aged 18-54.

Digit Force Contributions

The relative contributions of the fingers that were found as a result of this study were as follows, 25% for the index, 30% for the middle, 25% for the ring, and 20% for the pinky. These percent contributions remained constantly across nearly all comparisons. The only ones where significant difference was found were between advanced and intermediate sport climbers at VW (figure 1), whether or not they had a history of finger injuries (figure 2), and based on the average length of the fingers for males (figure 3).

In an examination of the advanced versus intermediate sport climbers, the percent contributions are found to be more evenly dispersed among the fingers in the intermediate climbers. The first three fingers of the advanced climbers are more heavily favored, with the middle finger taking on the great proportion of the load. It is unclear as to why this discrepancy occurred because there is no previous literature on this topic as it pertains to climbing.

Subjects in this study who had never suffered from a finger injury carried 3.89% of the total load on their ring finger compared to the subjects who had suffered a finger injury in the past. Although these results can only be generalized to this population, this is suggestive of the fact that finger injuries can have a lasting effect and can be exceedingly difficult to fully recover from.

Looking at just the males, there was a difference in the digit force contributions of the index and pinky fingers. Male subjects with an average finger length less than 9.14 cm carried a greater proportion on their index finger, whereas, males with an average finger length greater than 9.14 cm carried a greater proportion on the pinky. As demonstrated by figure 3, the load in those with a shorter average finger length was more evenly dispersed throughout the first three fingers with a sharp decline in the pinky. In those with a longer average finger length, the load was more evenly dispersed among all four fingers.

This is due to the fact that males with a shorter average finger length tended to have a disproportionally short pinky. This short pinky led them to either having to adjust their gripping position in order to fit it on a hold or to leaving off of the hold entirely. The latter option meant that it would not be subjected to the same degree of use as the first three fingers. This chronic underuse could have led to it being disproportionally weaker than the other three fingers.

This study found relative contributions for the fingers that differed from previous studies. MacDermid, Lee, Richards, and Roth (2004) found the percent contributions of the fingers to be 25%, 35%, 25%, and 15%, for the index, middle, ring, and pinky, respectively. Another study, conducted by Li (2002), found that the index accounted for 32%, the middle for 33%, the ring for 24%, and the pinky for 12% of the total gripping force. The reasons for these discrepancies largely stemmed from the fact that the previous two were not climbing-specific by design.

MacDermid et al. (2004) and Li (2002) both had their participants perform the tests while in a seated position. This meant that the subject's wrist and elbow were arranged on the same horizontal plane and the fingers produced force in the anteroposterior direction. These authors, however, recorded the digit force contributions via the use of individual finger pad force plates on their apparatus. This was in contrast to the current study, which determined the relative contributions as a proportion of the sum total of each individual finger. The distal interphalangeal (DIP) joint was more more flexed in the current study to better emulate a true open hand grip position. The varying degrees of flexion in the DIP joint would utilize the flexor digitorum profundus and the flexor digitorum superficialis in different proportions. In addition, Li (2002) measured her subjects via a continuous recording, as opposed to the MVC style used by MacDermid et al. and in this study.

Finger Length and Force Production

Moderately strong parabolic relationships were found for two of the fingers in level 3 (advanced) climbers. These included the index and pink fingers. The parabolic relationship demonstrates that there is an optimal length relative to someone's body height for these fingers.

For the index finger of my participants, the optimal length was found to be at 5.08% of their body height with the highest recorded percent of body weight loaded onto the finger being 27.44%.

The optimal length for the pinky finger of my participants was found to be at 4.26% of someone's body height. MacDermid et al. (2004) was the only previous study found that examined the relationship between finger length and strength. In that study they found those two variables to be moderately correlated in a linear fashion.

Interestingly, for this population, both of these finger's optimal length was within a 0.02% deviation from their respective mean lengths.

Relative Strength of the Fingers

The relative strength in the full open hand grip of boulderers was found to be greater in the elite than in the advanced. This is congruent with previous studies that have evaluated the strength of climbers. (Michailov, Mladenov, & Schöffl 2009; Schweizer & Furrer 2007; Watts

2004) In order to keep advancing through the grades that benchmark climbing ability, the relative strength of the forearm flexors must continue to improve.

However, when examining the individual fingers relative strength, no significant difference was found for any single one. The reasons for this are unclear, although this could be due to the existence of a force deficit. In a review of the literature on this topic, no previous studies were found, so no comparisons can be made between this study and the literature.

For intermediate and advanced sport climbers, there was no significant difference found between the two groups in the full open hand grip strength. This is contradictory to the previous literature, where it has been demonstrated that the relative strength of the forearm flexors is of the utmost importance. The index finger was the only one that presented a difference between the two groups.

The body mass between the two sport climbing groups was found to different, with the advanced climbers being significantly lighter. The previous literature on this topic is mixed because the more important variable is the relative strength of the forearm flexors.

Limitations

This study unfortunately was not without limitations. First, there was only 21 participants so while the results are interesting, they cannot be generalized past the entire population. To evaluate the individual finger contributions, the finger forces were assessed by the sum total of all of the fingers. Previous studies employed the use of individual force pads, however, they did not measure climbers, nor did they use a climbing-specific testing position. Also, fatigue was not controlled for. The participants were not told to climb the day before. They were only told not to climb the day of the testing. Many participants did not have experience pulling with only one finger. This may have created a mental barrier for some participants because they were afraid of getting injured. Therefore, a true max would not have been recorded. Lastly, due to the fact that participants were tested at all times of day, there may have been variations in the ambient conditions at Vertical World.

Future Research

In the future research should focus on determining the optimal length of the fingers in climbing populations. This study found an optimal length for the index and pinky, but there was no correlation for the middle and ring fingers. Furthermore, it would also be beneficial to evaluate the contributions of the fingers using individual force pads while in a hanging position. Other areas of research should include more about the importance of the relative strength of the individual fingers. This study only found a significant difference in the relative strength of the index finger of sport climbers. This topic needs to be further evaluated in a more targeted fashion to determine just how important the individual fingers truly are.

Conclusion

In conclusion, found a relative contribution for the individual fingers that remained constant across nearly all variables. Those contributions were 25%, 30%, 25%, and 15% for the index, middle, ring, and pinky, respectively. Additionally, the finger length of the index and pinky was found to have an optimal length relative to their body height among the participants. Both of these variables were untested in a climbing setting and this opened the door for future research to be done. How the fingers interact with one another and by themselves is of great importance to climbers of all abilities and because of this needs to be evaluated further.

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