International Journal of EXERCISE SCIENCE

Original Research

Acute Handgrip Fatigue and Forearm Girth in Recreational Sport Rock Climbers

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ABSTRACT

International Journal of Exercise Science 15(4): 834-845, 2022. Indoor sport rock climbing has been increasing in popularity both recreationally and competitively. Despite this increase in popularity, the physiological responses to sport climbing as an exercise to specific muscle groups are not well defined. The purpose of this study was to quantify the change in handgrip strength over a 30-minute bout of continuous climbing, specifically in intermediate-level sport climbers. Ten intermediate rock climbers (age = 27 ± 2 years; climbing experience: 7.3 ± 1.5 years) completed baseline handgrip strength and forearm girth measurements. Each participant ascended one of two 5.9 difficulty routes as many times as possible in 30 minutes. After each ascent, heart rate was obtained, and handgrip strength and forearm girth were measured. Data were analyzed using repeated-measures ANOVA with significance set at $\alpha < 0.05$. Dominant arm handgrip strength decreased by 22%, and non-dominant handgrip strength reduced by 23%. Dominant and non-dominant forearm girth increased by 4.5% and 4.4%, respectively. Weak but significant negative correlations were observed between handgrip strength and forearm girth in dominant ($r = -0.311$, $p = 0.001$) and non-dominant limbs ($r = -.491$, $p = 0.001$). These results indicate a relationship between increased forearm girth and decreases in muscular strength. Since handgrip strength decreases substantially during a 30-min climb in intermediate rock climbers, this population would be advised to carefully monitor recovery time between bouts.

KEY WORDS: Indoor climbing, repetitive ascents, forearm strength, recovery time, recreational climbers

INTRODUCTION

Rock climbing has increased in popularity since the first Rock Climbing World Cup in 1989 (8). Competitions for rock climbing include the combined disciplines of speed climbing, bouldering, and sport climbing. In speed climbing, a standardized route is completed in the shortest time.

Bouldering involves completing short routes or "problems" (10). Sport (or lead) climbing involves a timed-ascent along pre-set routes (18, 22). The sport has increased as a means of recreational fitness, with 3,000 new people trying it every day (1). In the United States, the Yosemite Decimal System (YDS) is used to grade sport climbing routes, and the open-end difficulty scale currently ranges from 5.10-5.15d. According to the International Rock Climbing Research Association (IRCRA), lower grade climbers climb from 0.1-5.9 (YDS), intermediate females climb from 5.10a-5.11a, and intermediate males climb from 5.10a-5.11c (6).

Indoor sport climbing is most commonly investigated (1, 11, 12, 14, 18, 23). Previous studies in rock climbing have explored the physiological response of handgrip strength in elite climbers (5.12d-5.14a for males and 5.12d-5.14d), recreational (5.1-5.9), and non-climbers (9, 23, 24). Grip strength is significantly greater in elite compared to recreational climbers and physically active non-climbers (no difference between recreational and non-climbers; rest period between repetitions not specified) (9). While maximum finger curl force was reduced in experienced climbers following eight 60-sec bouts on a hang-board, the difference was not significantly different using 1- or 3-min recovery periods (23). Finally, a 22% decrease in handgrip strength (average of right- and left-hand measures) was observed in experienced rock climbers who completed continuous 5.12a YDS laps until a fall (mean time = 13 min), with 10-sec rest periods between laps.

Although rock climbing has increased in popularity in recent years, the physiological responses to climbing are not vastly studied relative to other sports (18). It is essential to understand physiological responses to succeed as an athlete or as a coach to train athletes for improvement and success properly. Rock climbing is a unique sport requiring excellent upper limb strength, specifically in the finger and wrist flexors (23). During climbing, forearm strength is essential because the sport involves sustained and intermittent isometric forearm muscle contractions (2) in coordination with lower body hip rotation to stabilize the center of mass near the wall. In climbing, the force contact with most holds is generated by body mass along the gravitational line. The external force pulls the hand onto the hold with muscular force, maintaining the specific hand position against the external force (23).

Previous research has indicated that elite climbers' handgrip strength decreases by 22% during a climb to fatigue, with force averaged across both dominant and non-dominant hands (24). However, to our knowledge, the importance of this strength as it pertains to intermediate sport rock climbers has not been assessed, nor evaluated in this population by individual limb (i.e., dominant and non-dominant hands). A primary purpose of this study was to quantify the change in handgrip strength over a 30-minute bout of continuous climbing, specifically in intermediate sport climbers. Because rest time has been prescribed in previous studies [from 10-sec (24), to 3-min (23)], the current study was designed to characterize preferred recovery duration between bouts. An additional aim was to quantify changes in forearm girth and determine if a relationship exists with the change in strength observed. It was hypothesized that handgrip strength would decrease throughout the 30-minute bout of continuous climbing and that forearm girth would increase. Additionally, it was hypothesized that these two variables would have a strong negative correlation with one another.

METHODS

Participants

Mean 1-min hang durations from Watts et al. were used to determine an effect size of 0.801 (23), and with an alpha level of 0.50 and power of 0.80, a total sample size of 6 was deemed appropriate (7). To be conservative, a total of 10 subjects (7 males, 3 females) were recruited via announcements made in outdoor recreation classes [age = 27 ± 2 years (mean±SE); height = 174.5±1.9 cm; mass = 68.14 ± 2.6 kg; body fat % = 15.75±2.4 %; climbing experience = 7.3±1.5 years; typical range of grades climbed = 5.7-5.12 (YDS)]. This study was approved by the Biomedical Research Institutional Review Board (approval #1164228) and carried out by the ethical standards of the Helsinki Declaration and the International Journal of Exercise Science (16). At the start of the visit, all participants completed a health risk questionnaire and a climbing history questionnaire, assessing climbing history and current climbing ability. Participants were informed of the purpose, protocol, and risks and associated with the study before providing written, informed consent. Those classified as “moderate risk” or had an implantable device (such as a Pacemaker), or had orthopedic, cardiovascular, respiratory, or metabolic conditions; less than one year of climbing experience, less than a 5.9 (YDS) top rope on sight climbing ability, or any upper limb injuries were excluded from the study.

Protocol

Participants reported to the indoor climbing wall for testing on one occasion. Participants completed the anthropometric measures of height (self-reported), weight, and estimation of body fat % (Tanita TBF-521 Bioelectrical Impedance). Participants were then assessed for baseline handgrip strength (Takei 5001 Hand Dynamometer) and baseline forearm girth via tape measure around the widest part of the forearm. Baseline handgrip strength was measured using three maximal effort trials on each hand (approximately 3 seconds each trial). The highest value out of the three trials was recorded as the baseline for the participant. According to questionnaire responses, participants climbed intermediate difficulty routes (5.9-5.10d) most often.

Rock Climbing Protocol: After anthropometric measurements were completed, the climbers were instructed to put on their climbing gear (rock climbing shoes and harness) and tie into the top rope with a retraced figure-8 knot and belayed by one of the investigators. The participants were then reminded of the protocol: to ascend one of the two 5.9 routes on top rope for as many times as possible over 30 minutes, with heart rate, handgrip strength, and forearm girth being measured after each ascent and descent. Two identical 5.9 routes were set on the same face of the climbing wall using the same hold types to ensure the routes were alike (see figure 1). Climbers were instructed to stay on route (using only one color for both hands and feet) and climb continuously from start to finish, with breaks only at the bottom (after being lowered) as needed. The amount of time each climber took for recovery breaks were recorded and reported in seconds. Climbers were able to use features on the wall, and the arête along with the designated climbing holds. Heart rate was obtained during each break by palpating the radial artery, as palpation has been reported to be accurate immediately following exercise (17). Handgrip strength was assessed using maximal effort as previously described, and forearm girth was measured at the widest part of the forearm.

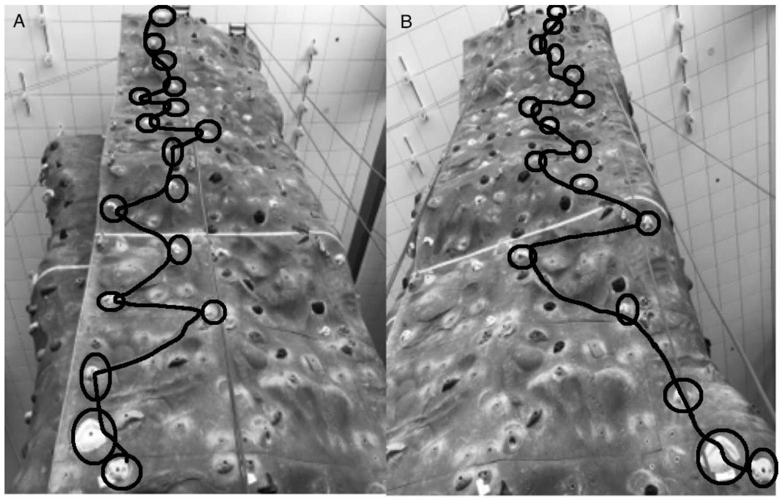


Figure 1A. Top-rope route 1 (5.9 YDS). **1B.** Top-rope route 2 (5.9 YDS).

Statistical Analysis

Data are presented as mean ± SE. IBM SPSS Statistics 23 Software (Armonk, NY) and Microsoft Excel 2016 (Redmond, WA) were used to analyze results. A repeated measures ANOVA was used to compare the means of the changes in handgrip strength and forearm circumference changes over the 30-minute bout of climbing for dominant and non-dominant hands. A repeated measures ANOVA was also utilized to evaluate duration of rest periods utilized over quartiles of the bout of climbing. Effect size (ES) from repeated measures ANOVA was reported as partial Eta squared (η^2), with 0.01 = small effect size, 0.06 = medium effect size, and over 0.14 = large effect size.

A correlation between handgrip strength and forearm circumference changes for the first 50% of the climb was also determined for dominant and non-dominant hands. Additionally, paired t-tests were used to compare handgrip strength changes between dominant and non-dominant hands. Cohen's *d* ES were interpreted as 0.00 to 0.20 = very small, 0.20 to 0.50 = small, 0.50 to 0.80 = medium, 0.80 or above = large.

Any differences between the intensity of the two routes (A and B) were determined by evaluating heart rate (percent of age-predicted maximal) using an unpaired t-test.

An α-level of < 0.05 was used to indicate significance. Utilizing the Shapiro-Wilk test, all data were determined to be normal and met Mauchly's test of sphericity.

RESULTS

All participants were able to climb a minimum of four complete ascents, with a mean of 15.8 ± 5.8 ascents of either route over the 30 minutes. The intensity of the two routes was matched by heart rate and was not significantly different (Route A % of age-predicted HRmax = 73.2 ± 1.7, Route B % of age-predicted HRmax = 68.8 ± 1.7, p = 0.100, d = 1.18, large ES). The average heart rate of all intermediate rock climbers across both routes over the 30-min bout was 71 ± 4.2% of the age-predicted HRmax.

Changes in handgrip strength and forearm girth were assessed for all participants in the study. Since all participants completed a different number of ascents, change in handgrip strength and forearm girth was assessed in quadrants of individual participants' climbs: *i.e.,* the first 25% of the 30-minute bout, 50%, 75%, and 100%.

Handgrip strength: Dominant arm handgrip strength decreased by 22.1% throughout the climbing bout (see figure 2a). During the first quarter of the climbing bout, handgrip strength decreased by 11.8%. Halfway through the climbing bout, handgrip strength decreased by 17.5%, and 75% through the climbing bout handgrip strength decreased by 19.7%. There was a decrease in handgrip strength from the pre-climb to all quartiles (25% p = 0.002; 50% p < .001; 75% p = .001; 100% p = .003, η_p^2 = 0.924, large ES) respectively.

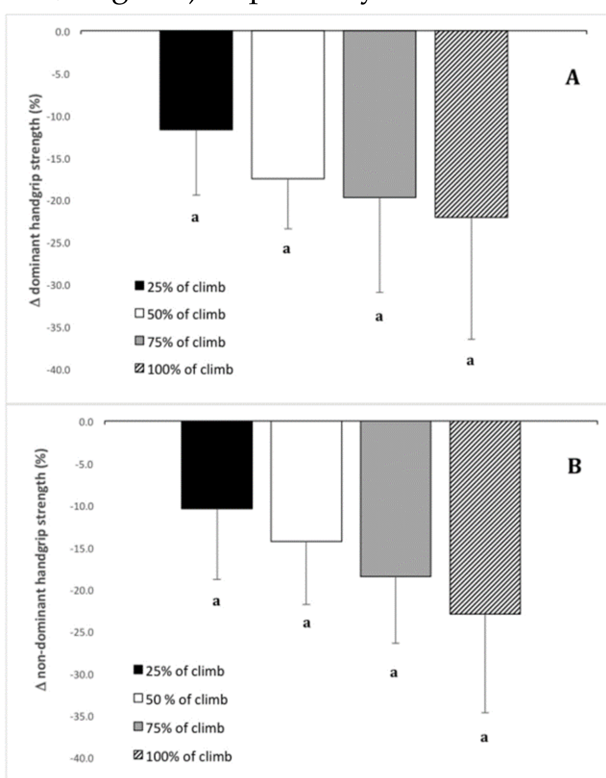
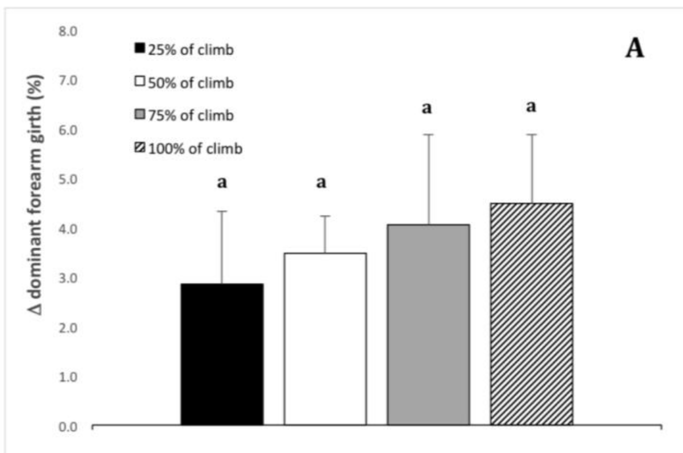


Figure 2A. Change in dominant handgrip strength of participants (N = 10) who completed a 30-min climbing session, expressed in quartiles of time. Expressed as mean and standard deviation. **2B.** Change in non-dominant handgrip strength of participants expressed in quartiles of time. a = significantly different compared to baseline (p < 0.05).

Non-dominant handgrip strength decreased by 23% throughout the climbing bout (see figure 2b). During the first quarter of the climbing bout, handgrip strength decreased by 10.5%. Halfway through the climbing bout, handgrip strength decreased by 14.3%, and 75% through the climbing bout handgrip strength decreased 18.5%. Similar to what was observed in the dominant hand, there was a decrease in handgrip strength from pre-climb to each successive quartile (25% p = 0.049; 50% p = 0.003; 75% p < .001; 100% p = 0.01, η_p^2 = 0.726, large ES) respectively.

Forearm girth: Dominant forearm girth increased at post by 4.5% (p = 0.01), and increases were significantly greater from baseline at every quartile of time (25% p = .002; 50% p = 0.01; 75% p = 0.01, η_p^2 = 0.995, large ES; see figure 3a). Non-dominant forearm girth also increased at post by 4.4% (p = 0.01), and from pre to each quartile thereafter (25% p = 0.01, 50% p = 0.01; 75% p = 0.01, η_p^2 = 0.908, large ES; see figure 3b). Additionally, compared to the first quartile of the climb (i.e. 25%), non-dominant forearm girth was increased at the other quartile time points (50% p = 0.034; 75% p = 0.038).



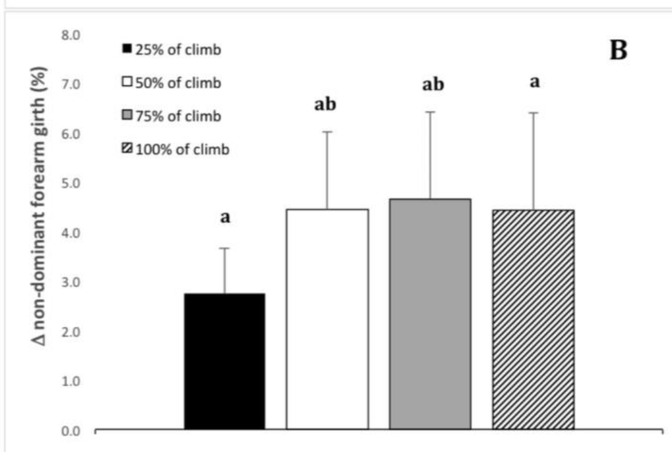


Figure 3A. Change in dominant forearm girth of participants (N = 10) who performed a 30-min climbing session, expressed in quartiles of time. **3B.** Change in non-dominant forearm girth of participants expressed in quartiles of time. a = significantly different compared to baseline (p < 0.05). ab = significantly different compared to the first quarter of the climb (p < 0.05).

Relationship between handgrip strength and forearm girth: Concerning the dominant limb, a weak but significant negative correlation existed between handgrip strength and forearm girth when the entire data set was considered (r = -0.311, R^2 = 0.0192, p = 0.001; see figure 4a). As there were no significant changes in the dominant limb for either handgrip strength or forearm girth after the halfway mark of the climb, we also chose to determine the relationship of these variables over the first 50% of the bout. In this regard, there was a significant negative correlation between dominant limb handgrip strength and forearm girth in intermediate rock climbers over the initial half of the climb (r = -.392, R^2 = 0.1537, p = 0.001). When the entire data set was considered for the non-dominant limb, there was a weak but significant negative correlation observed (r = -.491, R^2 = 0.2416, p = 0.001; see figure 4b). Similar to the dominant limb, a weak but significant negative correlation was observed when data from the initial 50% of the climb was considered (r = -.400, R^2 = 0.1602, p < .001).

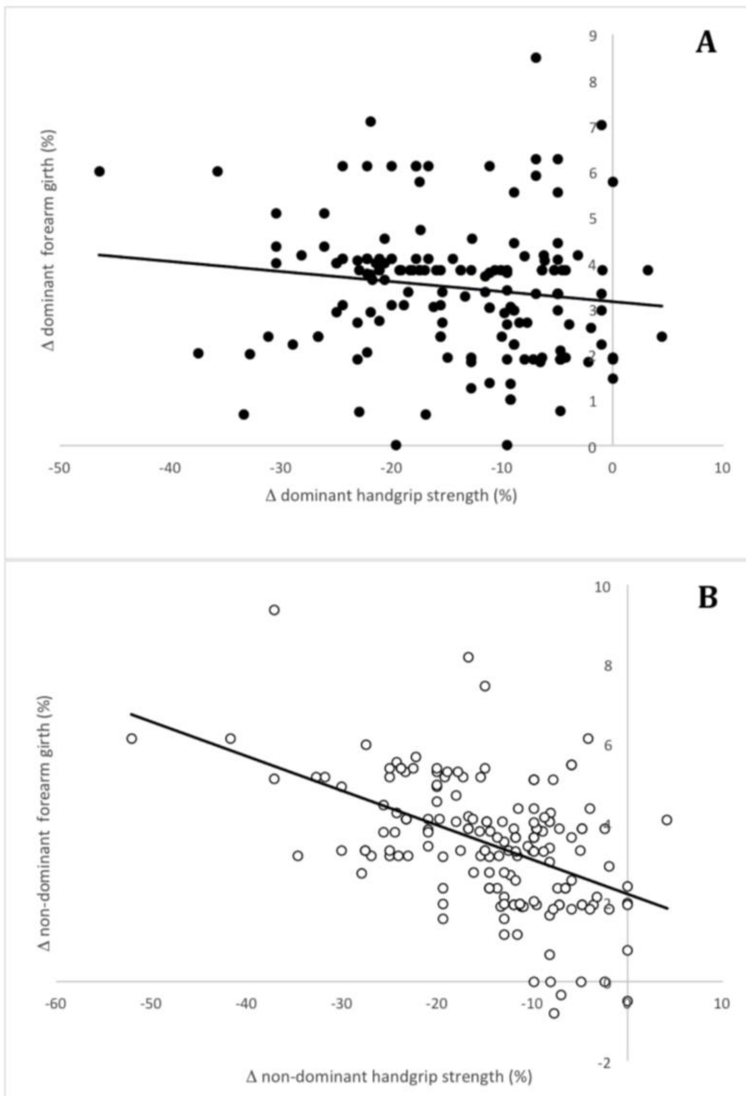


Figure 4A. Relationship between dominant limb handgrip strength and forearm girth over 30-min indoor rock-climbing bout in intermediate climbers (p = 0.001). **4B.** Relationship in the non-dominant limb (p = 0.001).

Rest Period: Rest periods between each climb were measured and are reported as an average in seconds for each quartile of the bout. No differences were detected for rest time between any quartile of time throughout the 30-min bout of indoor sport rock climbing (p = 0.923, η^2 = 0.013, medium ES). The average rest time taken between bouts during the first 25% of the climb was 75.3 ± 5.5 seconds and then 77.8 ± 10.6 seconds up to the halfway point of the protocol. The greatest amount of rest time occurred during the time period between 50% and 75% of the bout (82.7 ± 16.7 seconds), while the lowest rest time occurred from 75% through the remainder of the session (75.3 ± 15.2 seconds), perhaps due to the time pressure of completing more ascents before the end of the assigned climbing time.

DISCUSSION

The purpose of this study was to better understand the physiological demands of indoor sport rock climbing, specifically the occurrence of forearm muscle fatigue and change in forearm girth in intermediate climbers. Our hypothesis for the current study was that handgrip strength would decrease over the 30-minute course of continuous climbing, and forearm girth would increase. The results of our study showed a significant decrease in dominant (22.1%) and non-dominant handgrip strength (23%), as well as a significant increase in dominant (4.5%) and non-dominant forearm girth (4.4%). Additionally, there was a significant negative correlation for both variables in dominant and non-dominant limbs.

Rock climbing involves sustained and intermittent isometric forearm muscle contractions (2). Muscle fatigue is a common complaint in physical activity (including rock climbing) and it can be defined as an exercise-induced decrease in the ability to produce force (21). The results of our study show a 22.1% decrease in handgrip strength in the dominant hand and a 23% decrease in handgrip strength in the non-dominant hand. These findings are similar to what has been observed in elite climbers' handgrip strength when climbing to failure (decrease of 22%) (24). The participants in the previously mentioned study were instructed to climb continuously on an indoor sport climbing route (5.12a) until a fall occurred and were lead climbing (24), which is a more difficult type of climbing than top-rope as used in the current study. Handgrip strength was measured 20 minutes before climbing, one minute after climbing, and five, 10, and 20 minutes post-climb in elite climbers (24). To our knowledge, there has not been previous research on handgrip strength over a bout of climbing in intermediate climbers. The results from our study showed that handgrip fatigue progressively decreases in both the dominant and non-dominant hand while climbing. We found dominant handgrip to decrease by 11.7%, 17.5%, 19.7%, and 22.1% through each quarter of the climb, respectively. Handgrip decreased by 10.4%, 14.3%, 18.5%, and 23% respectively on the non-dominant hand.

It is common for climbers to attribute failure and/or the need for longer rest times to forearm/grip fatigue also known as the "pump". This "pump" occurs when the sensation of forearm tightness occurs and can cause one's climbing ability to decrease. Although this occurrence is referred to anecdotally, it has yet to be studied in the literature. To our knowledge, no investigation has been designed to observe the change in forearm girth over a bout of climbing. However, there have been observations that fatigue in climbing occurs with an increase in forearm girth and pain (15). Although forearm girth has not been measured, lactate has been used to measure fatigue in the peripheral muscles, mainly the forearms and upper body (3). A previous study looked at the effects of passive versus active recovery on lactate, and it was found that due to the increase in heart rate during active recovery, blood flow increases to the working muscles and is believed to enhance the removal of lactic acid (5). The mechanism behind forearm girth increasing during rock climbing can be attributed to the repeated isometric contractions of the forearm, which may result in a reduction in blood flow and increased swelling of the forearm. As one contracts the same muscles and repetitively maintains the contraction, strength output decreases as swelling and pain increases. The participants in the present study self-selected to have a relatively short recovery period in between climbs, and primarily spent this time in passive recovering. This passive recovery period could contribute to the decrease in blood flow to the working muscles of the upper body and forearms. In addition to active recovery enhancing blood flow in the peripheral muscles in climbers, cold water immersion is an effective recovery mode (11). Cold water immersion is a technique that is believed to induce localized vasoconstriction, which reduces acute inflammation in the forearms (11). Previously, vascular characteristics of rock climbers have been compared to untrained individuals, where brachial artery diameter and blood flow were measured (20). It was hypothesized that rock climbers would show enlarged artery diameter and enhanced capillary filtration and capillary density (4). In climbers, resting arterial diameter was 11.8% greater than in non-climbers, and capillary filtration capacity was 27.4% greater in climbers than non-climbers (4). These results demonstrate that rock climbers tend to have increased forearm vasculature, indicating that repeated isometric ischemic conditions enhance vascular adaptations (20). The results of our study show a 4.5% increase in forearm girth in the dominant hand and a 4.4% increase in forearm girth in the non-dominant hand. Additionally, the results of our study show a significant negative correlation between handgrip strength and forearm girth (both dominant and non-dominant), providing evidence that as handgrip strength decreases, forearm girth increases. It would be interesting to perform a similar protocol on untrained climbers, assessing these variables.

Along with forearm muscle fatigue, rock climbing causes cardiovascular stress while climbing. In the current study, heart rate during climbing was assessed to quantify the intensity of this physiological stress. The mean heart rate achieved over the 30-minute bout was 71 ± 4.2% of age-predicted HR_{max}. Previous research measuring heart rate for beginner and recreational climbers ranged from 76-90% and 71-79% respectively (12). According to this data, it is clear that beginners' heart rate tends to be higher while climbing when compared to more experienced climbers. Previous research also shows that experienced climbers have lower energy expenditure while climbing than beginners (14). This suggests that skill and technique play an important role in energy expenditure while climbing, and this could influence heart rate (12). The heart rate data recorded in our study is similar to that of previous investigations (8, 12-14).

Rest time in between climbing bouts has not been extensively researched. One study assessed the effects of active versus passive recovery on post-climbing blood lactate and handgrip strength (22). Although there are no recovery mode guidelines, passive recovery during and after climbing is assumed to be more common than active recovery. The results of the study by Watts et al. regarding active versus passive recovery and its effects on handgrip could not be compared because the passive recovery group did not experience a significant decrease in handgrip strength from the climbing bout (22). The authors concluded that active recovery produced blood lactate levels equal to baseline level within 20-minutes post-climb (22). However, these rest times were not assessed in between multiple ascents as they were in our study. A systematic review looking at optimal rest time during resistance training shows that 2-5 minute rest intervals may produce the greatest power-strength benefits, however rest interval length may vary based on athlete's training experience, age, fiber type, and genetics (19). The results from our study show a preferred mean rest time between climbing intervals to be 78 ± 3.3 sec. This rest time approximately falls in line with the recommended rest time for resistance training. It is possible that with longer rest times, handgrip strength would not decrease as substantially.

This study assessed the change in handgrip strength and forearm girth in intermediate climbers over a 30-minute bout of climbing. A limitation in this study is that we could have assured all participants climbed for 30-minutes, instead of including both climb time and rest time during the 30-minute bout. Ensuring that participants climbed for 30-minutes total could better quantify changes in forearm girth and its correlation to handgrip strength. Also, pre-climb nutrition was not controlled. Additionally, we measured forearm girth at the widest part of each individual's forearm; however, measuring girth more centrally could better explain the forearm "pump" that occurs while climbing. The tightness sensation occurs in the medial/distal area of the forearm, rather than the widest part, which is closer to the elbow. Future studies should regulate climbing time, measure forearm girth distally, or look at blood flow via ultrasound and/or water displacement to better explain the "pump" sensation that occurs while climbing.

The current results can contribute to the existing literature in helping to better understand the physiological demands of indoor sport rock climbing, specifically the change in handgrip strength and forearm girth while climbing. As a result of better understanding this common muscle fatigue, indoor rock-climbing facilities and/or rock-climbing instructors could better prescribe recommendations for time of climbing bouts and rest time which may maximize time spent on climbing walls. These results present valuable information for intermediate rock climbers, which make up the majority of the indoor sport climbing population.

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