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Heart Rate Response, Duration, Grip Strength, and Anthropometric Characteristics in Recreational Indoor Rock Climbers

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ABSTRACT

Recreational indoor rock climbing continues to increase in popularity as the inclusion of climbing in the 2020 Olympics approaches. Despite the popularity of the sport there is a lack in research regarding the cardiovascular responses of recreational indoor climbers. Additionally, the importance of body composition and grip strength has been established in elite climbers yet has been overlooked in recreational climbers. Therefore, the purpose of this study was to characterize the physiological and anthropometric characteristics of recreational indoor climbers. We hypothesized that heart rates and climbing durations would meet the standards set by the American College of Sports Medicine (ACSM) and Center for Disease Control and Prevention (CDC) for eliciting health benefits and that grip strength would show signs of fatigue over the course of a typical session. One hundred and twenty-one male and female adult recreational climbers participated in this study. Following informed consent, subjects completed a questionnaire and were instrumented with a heart rate monitor (Polar V800) which recorded heart rate and duration. A pre-climb and post-climb grip strength evaluation was performed using a hand grip dynamometer to assess maximal grip strength and calculate strength to mass ratio (SMR) and fatigue. Participants were 30.9 ± 8.3 years old and had participated in climbing for 5.6 ± 6.5 years. Average heart rates during climbing sessions was 122.3 ± 14.5 bpm and session duration was 90.6 ± 31.3 minutes. Mean grip strength was 49.9 ± 11.2 kg while SMR was 0.71 ± 0.14 and fatigue was 13.1 ± 11.6%. Results from this study suggest that recreational indoor climbers achieve heart rates in the ranges set by the CDC and ACSM. Heart rates are sustained long enough to contribute toward weekly exercise recommendations. Grip strength data suggested that forearm muscle fatigue may limit climbing durations.

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INTRODUCTION

Rock climbing is a growing sport that is increasing in popularity annually. While it is difficult to accurately track, some estimate that up to 3000 people per day try climbing for the first time (Aras & Akalan, 2016). This increased participation in rock climbing may be a result of increasing numbers of indoor rock-climbing facilities, which make the sport more accessible to a larger population. It is likely that participation rates in rock climbing will continue to increase with the inclusion of rock climbing in the 2020 Olympics (Olympic.org, 2016). Despite these facts there is surprisingly a paucity of literature describing the physiological demands of indoor rock climbing.

Most data published about the characteristics of rock climbing has been performed on small sample sizes of elite male climbers. Studies in the past have looked at the aerobic demands of rock climbing by measuring oxygen uptake (VO2) and found that rock climbing may require a large enough portion of a person's peak oxygen uptake to elicit positive adaptations in aerobic fitness (Booth, Marino, Hill, & Gwinn, 1999; Watts & Drobish, 1998). Other research on VO_2 in rock climbing found that energy expenditure was similar to running between an 8:00 and 10:30 minute mile pace, and suggested that climbing may be good for increasing cardiorespiratory fitness (Mermier, Robergs, McMinn, & Heyward, 1997). A more recent review of the physiology of climbing suggested that rock climbing does indeed require a significant portion of a person's aerobic capacity (Sheel, 2004).

Measuring VO_2 is the standard for assessing aerobic fitness though the linear relationship between heart rate (HR) and VO_2 allow for monitoring HR as an effective way to assess physical activity (Limonta et al., 2018). The Centers for Disease Control and Prevention (CDC) and American College of Sports Medicine (ACSM) have established the guidelines of 150 minutes of moderate (64-76% max HR) or 75 minutes of vigorous (76-96% max HR) physical activity per week (American College of Sports Medicine, 2013; Centers for Disease Control and Prevention, 2016). Following these guidelines has been shown to elicit health benefits such as reduced risk of chronic disease including diabetes and heart disease (CDC, 2019). Heart rates in elite climbers during climbing have been reported to range between 73 and 89% of age predicted maximum heart rate (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Booth et al., 1999; Giles, Rhodes, & Taunton, 2006; La Torre, Crespi, Serpiello, & Merati, 2009; Mermier et al., 1997). These findings suggest that elite rock climbers achieve heart rates during climbing that have been reported to have cardiovascular benefits. However, it should be noted that these heart rates may be slightly exaggerated due to a disproportionate rise in HR compared to VO_2. This disproportionate rise in HR has been attributed to the repetitive use of isometric contractions during climbing (Limonta et al., 2018; Mermier et al., 1997; Sheel, 2004). Given that much of the previous research has focused on elite climbers, it is unclear if recreational climbers have similar heart rate responses during climbing and if so what percentage of their time in a climbing gym is spent in these heart rate ranges.

Although research on climbing is limited, body composition and muscle strength of elite climbers are two additional areas that are commonly reported in the climbing literature. Specifically, previous research has reported that elite male climbers typically have small to moderate stature and low body fat percentages (Espana Romero et al., 2009; Watts, Martin, & Durtschi, 1993). The low body fat percentages in climbers leads to higher grip strength to body mass ratios compared to non-climbers (Giles et al., 2006; Mermier, Janot, Parker, & Swan, 2000; Watts et al., 1993). These findings suggest that both body composition and grip strength are likely two physiological variables that contribute to the success of elite climbers through increasing strength to mass ratio (Mermier et al., 2000; Watts et al., 1993) . However, there is currently a lack of data characterizing the body composition and grip strength of recreational climbers, which utilize climbing gyms for training. Furthermore, little is known about the impact that a single climbing session has on muscular fatigue in the forearm.

The purpose of this study was to characterize the physiological and anthropometric characteristics of recreational indoor rock climbers. Specifically, this study aimed to characterize heart rate responses, climbing session and activity duration, anthropometrics, and forearm muscle strength and fatigue in recreational indoor climbers. Heart rate during a climbing session was the primary outcome of the study. We hypothesized that heart rates and climbing durations in recreational climbers would meet the ranges specified by the ACSM and CDC as eliciting health benefits. We also hypothesize that grip strength to mass ratio will be similar to values seen in elite climbers and grip strength will fatigue over the course of a climbing session.

METHODS

Experimental Approach to Problem

No studies have examined the heart rate response and duration of physical activity in recreational indoor rock climbers. In this study a Polar V800 heart rate monitor was used to measure participant's heart rates as an index of exercise intensity. During the climbing session the duration of five different activities (Rest, Belay, Top Rope, Lead, and Boulder) were also recorded by an observer throughout the course of the session. Heart rates recorded by the monitor were then matched to each activity recorded by the observer. Additionally, the current study examined recreational climber anthropometrics as well as pre and post climbing grip strengths. These measurements were taken at two local indoor rock-climbing facilities (Mesa Rim Climbing Centers).

Subjects

One hundred and twenty-one male (n=81) and female (n=40) adult recreational climbers between 19-64 years old were recruited at two local indoor rock-climbing facilities in San Diego County (Mesa Rim Climbing Centers). Recreational climbers were considered anyone climbing in a non-competitive environment at an indoor climbing facility. Subjects were informed of the risks and benefits of the study and written informed consent was obtained prior to participation in the study. All procedures were approved by the Institutional Review Board at California State University, San Marcos (IRB# 1157324). All participants completed a rock-climbing history questionnaire in which they answered questions about their rock-climbing experience and current rock-climbing participation rates. Subjects were excluded from the study if they had less than six months of climbing experience or participated in climbing less than twice per month regardless of experience.

Subject Characteristics

Of the one hundred and twenty-one subjects that participated in this study, eighty-one were male and forty were female. Subject characteristics stratified by gender are reported in table 1. On average the subject's age was 30.9±8.3 years old. Subject's average height and weight were 170.44±13.54 cm and 71.60±18.22 kg respectively. These heights and weights resulted in an average BMI of 23.43±2.77 kg/m^2 for the subjects. Whereas, measured body fat percentage for the subjects averaged 16.86±6.67 percent. Subjects self-reported an average of 5.55±6.49 years of climbing experience and a frequency of climbing 2.73±1.04 days per week.

Table 1. Descriptive Statistics of Subjects Stratified by Gender (mean ± SD)

	Total **n =121**	**Male** **n =81**	**Female** **n =40**
Age	30.92±8.25	30.58±8.16	31.60±8.48
Height (cm)	170.44±13.54	174.34±13.74	162.54±9.01
Mass (kg)	71.60±18.22	76.21±17.07	62.25±16.99
BMI	23.43±2.77	23.94±2.42	22.37±3.14
Body Fat %	16.86±6.67	13.90±5.24	22.78±5.12
Years Climbing Experience	5.55±6.49	6.12±6.96	4.38±5.32
Days Per Week Climbing	2.73±1.04	2.78±1.10	2.63±0.89

Materials and Protocol

After completing informed consent and questionnaires, subjects' anthropometric characteristics were measured. Height and mass were measured on a beam scale (Health O Meter, IL, US). Height and mass was then entered into an Omron HBF306C hand-held bioelectrical impedance analysis system (BIA) (Omron Healthcare, Hoofddorp, Netherlands) which was used to measure body fat percentage and to calculate BMI as kg/m^2. Following anthropometric measurements subjects maximal grip strength was measured in both hands using a hand grip dynamometer (Stoelting Co. IL, USA) connected to a Powerlab 4/35 data acquisition system (ADInstruments Inc., CO, US). A two-point calibration with a known weight was used to calibrate the device and convert the measurements from millivolts to kilograms. The dynamometer was adjusted per CDC guidelines to where the second joint of the index finger is at a 90-degree angle on the handle. Trials were performed standing with the arm at the side, palm facing inward (CDC, 2011). Maximal grip strength was determined by taking the highest of three trials for both the dominant and non-dominant hand. Following the measurement of grip strength, subjects were fitted with a Polar V800 receiver on their wrist and H7 Bluetooth heart rate transmitter around the chest just below the pectoralis major muscles (Polar Electro Inc., Kempele, Finland). A terry cloth wrist band was placed over the wrist to protect the watch from damage as well as to blind subjects from heart rate measurements. Following instrumentation, all subjects were instructed to engage in their normal rock-climbing activities. Subjects were also asked to refrain from other activities the facilities had to offer such as slack lining, weight lifting, and using cardio equipment until the climbing data acquisition session was complete.

During the climbing session heart rate (bpm) and duration (seconds) were recorded at one second intervals on the Polar V800 watch. Throughout the session subjects were also monitored by a research assistant who recorded start and stop times for six activities being assessed during this study. The six activities were warm up, top rope, boulder, lead, belay, and rest. Warm up was considered any pre-climbing activity to include stretching or light physical activity done before beginning the climbing session. Top rope climbing consisted of a rope passing through a top anchor between climber and belaying partner (Draper, Jones, Fryer, Hodgson, & Blackwell, 2010). Bouldering consisted of climbing on shorter routes without a rope, but with a mat underneath the climber for safety (Draper et al., 2010; Fryer et al., 2017). Lead climbing was defined as the climber clipping the rope into pre-set safety carabiners as he or she ascends the wall (Wright, Royle, & Marshall, 2001). Belaying referred to controlling a safety device for an ascending climber (Kaplan-Reimer, Sidener, Reeve, & Sidener, 2011). Lastly, rest was considered to be the absence of any of the previously described activities. Climbing activities were classified as top rope, boulder and leading while non-climbing activities were warm up, belaying, and resting. At the completion of the climbing session grip strength was re-assessed using the same methodology that was used for the pre-climbing measurement. Once the session was complete data acquisition was terminated and Polar Flow software was used to download data from the Polar V800 watch to a Microsoft Excel spreadsheet. Activities were then coded and matched to the appropriate heart rate on the excel spreadsheet for each subject.

Data Analysis

Data is reported as mean ± standard deviation (SD). Mean heart rate and session duration were directly compared to the exercise recommendations for cardiovascular fitness and health set by the ACSM and CDC of 150 minutes of moderate (54-76% max HR) or 75 minutes of vigorous (76-96% max HR) physical activity per week to determine if the subjects met these recommendations during recreational rock climbing. Heart rate and duration were combined and analyzed together to determine the amount of time participants spent in each HR range during a climbing session. Age predicted maximum heart rate was calculated using the ACSM recommended equation of 220-age (American College of Sports Medicine, 2013). Subjects were excluded if more than 5% of total heart rate data were missing (n=7). Based on exclusion criteria

114 subjects' heart rate data was analyzed. Hand grip strength, fatigue, and strength to mass ratio (smr) were also calculated for 119 subjects. Two subjects were not included in grip data analysis due to equipment malfunction. Hand grip fatigue was calculated as a percent change from pre-test to post-test. Strength to mass ratio was calculated by averaging the left and right grip strengths together and dividing by body mass. To compare mean HR, duration, and grip strength data by sex, unpaired t-tests were conducted. A subset of 29 climbers who exclusively participated in bouldering were also analyzed and compared to the remaining 92 subjects who participated in either rope climbing or multiple activities to determine differences in HR, duration, and grip strength data. All data manipulations were conducted in SAS 9.4 (Cary, SC). Statistical analyses were conducted in SPSS version 24 (Chicago, IL).

RESULTS

Heart Rate

Figure 1 represents the heart rate response of a typical climbing session for one participant. Average heart rate during climbing sessions was 122.3 ±14.5 bpm (64.9 ± 7.8% age predicted maximum HR) (Figure 2). Mean heart rate in beats per minute for warm up was 92.7 ± 15.3 (49.2 ± 8.1%), top rope 148.6 ± 20.2 (79.4 ± 10.4%), bouldering 135.9 ±13.4 (71.0 ± 7.2%), belaying 110.7 ±17.7 (59.1 ± 9.5%), resting 117.7 ± 16.4 (62.4 ± 8.7%) and leading 148.6 ± 15.4 (79.4 ± 8.2%) (Figure 2). When separated into climbing and non-climbing activities participants mean heart rates were 145.2 ± 18.6 bpm (77.0 ± 10.0%) for climbing and 115.0 ± 16.2 bpm (61.0 ± 8.5%) for non-climbing activities (p=0.001). There were no significant differences in heart rate between sexes for any of the climbing activities (Figure 2).

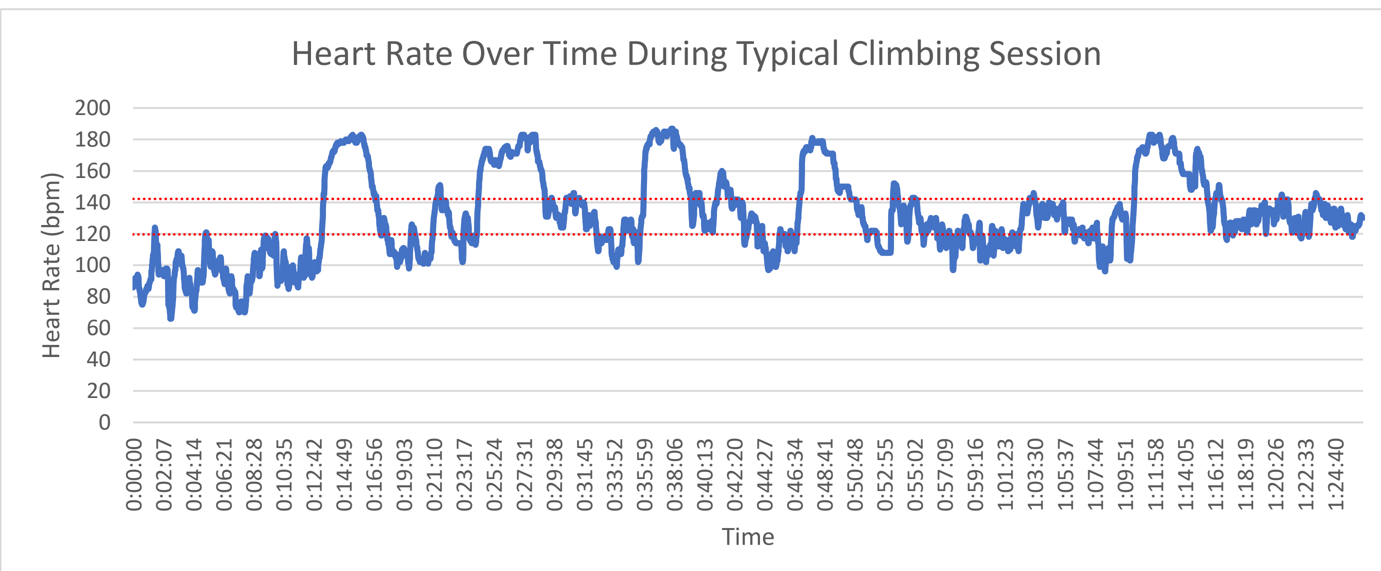

Figure 1: Heart rate data (beats per minute) collected in 1 second intervals from a single subject over the course of the entire climbing session. Red lines indicate 64% (119.7 bpm) and 76% (142.1 bpm) of age predicted maximum.

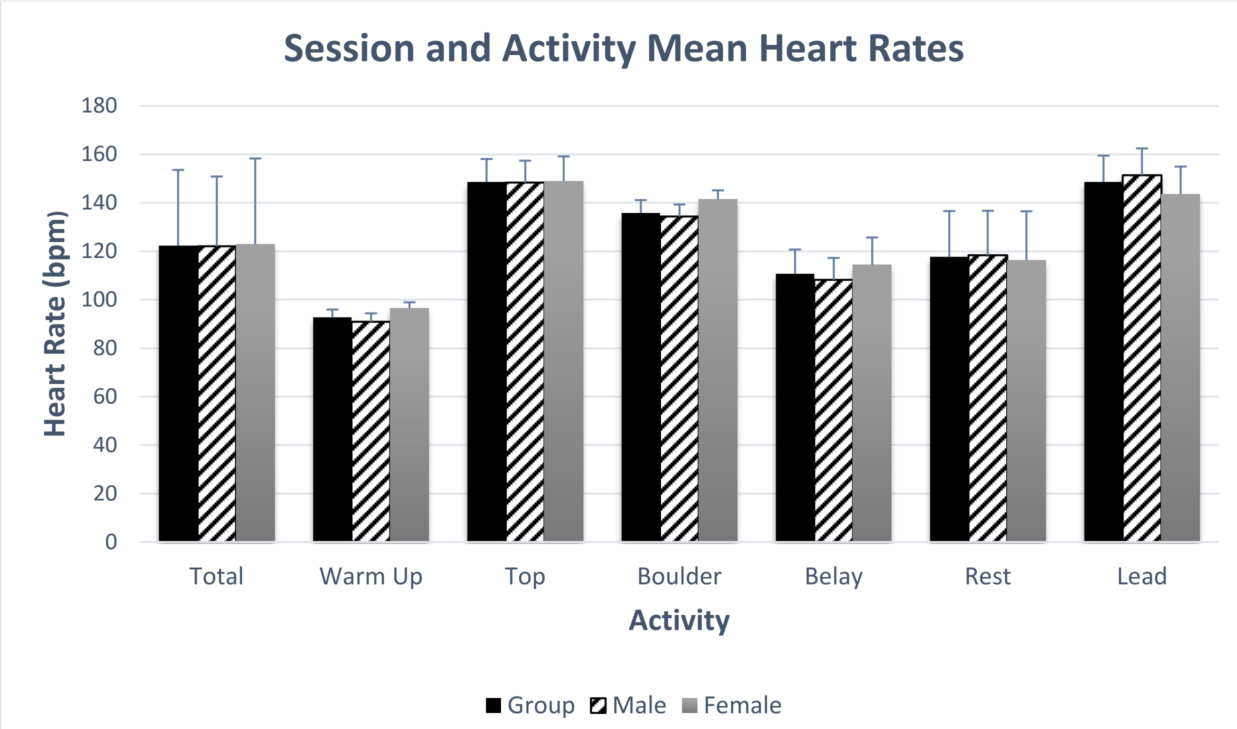

Figure 2: Mean HR in bpm for the total session and separated by activity. Means for the group, males, and females are displayed.

Duration

Session and activity duration in minutes for males and females is shown in figure 3. Mean climbing session duration was 90.6 ± 31.3 minutes with males averaging 87.6 ± 28.9 minutes and females 97.0 ± 35.3 minutes. Durations in minutes for each activity were 4.6 ± 3.2 (5.4 ± 3.4% of total time) for warm up, 20.9 ± 9.5 (22.1 ±9.0%) for top rope, 10.1 ± 5.3 (14.7 ± 9.5%) for bouldering, 22.8 ± 10.0 (23.4 ± 7.3%) for belaying, 47.1 ± 18.9 (53.0 ± 15.8%) for rest, and 18.7 ± 10.8 (15.9 ± 8.1%) minutes for lead. Males spent significantly more time bouldering (11.3 ± 5.0 minutes) than females (5.6 ± 3.8 minutes) per session ($p=0.002$). All other durations of climbing activities were not significantly different between males and females. As a group, participants spent an average of 21.8 ± 9.8 (24.1 ± 7.1%) minutes actively climbing and 68.9 ± 24.4 (76.0 ± 7.1%) minutes in other non-climbing activities ($p<0.001$).

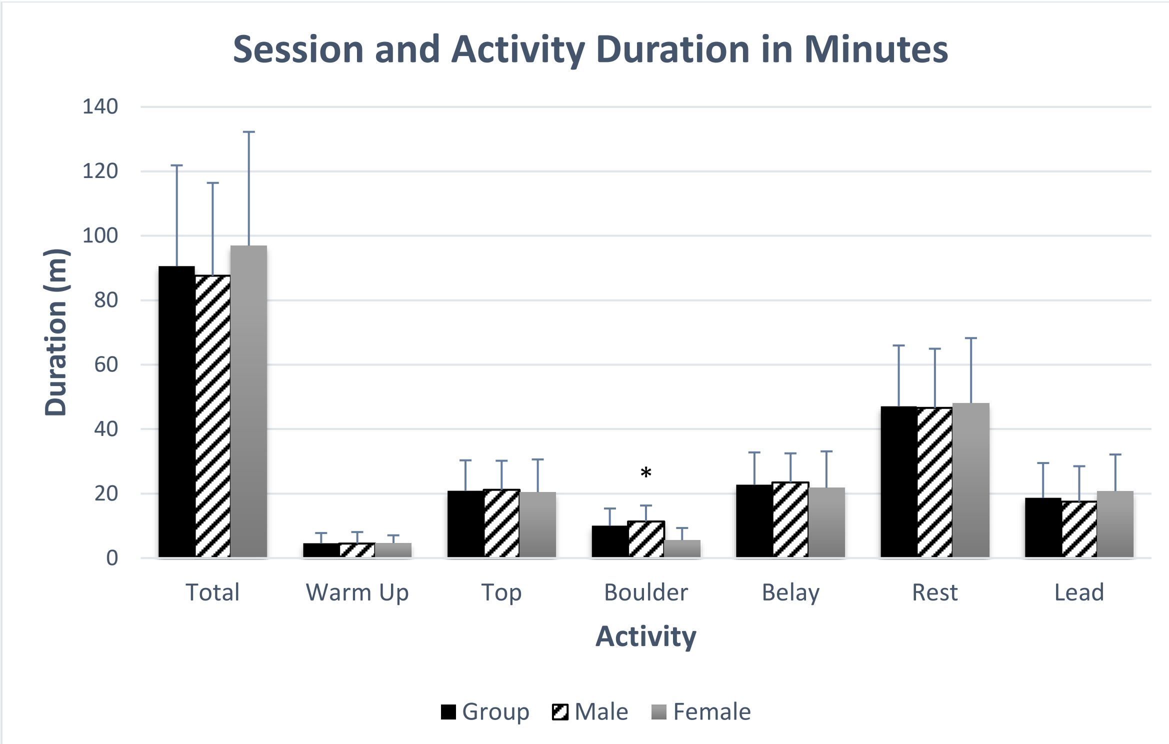

Figure 3: Mean duration in minutes for the total session and separated by activity. Means for the group, males, and females are displayed.

Duration and Heart Rate

When data from HR and duration are examined together recreational indoor rock climbers spent 20.1 ± 16.1 minutes (21.7 ± 12.6% of total time) with heart rates associated with moderate and 23.7 ± 17.7 minutes (26.4 ± 16.5%) vigorous or above intensity physical activity.

Grip Strength

Mean grip strength for the group was 49.9 ± 11.2 kg as measured during the pre-climb test. Male grip strength (55.8 ± 7.9 kg) was significantly greater than female grip strength (38.2 ± 6.8 kg) ($p<0.001$). Mean grip SMR was calculated as 0.71 ± 0.14 for the group. Grip SMR was significantly greater in males (0.75 ± 0.13) compared to females (0.63 ± 012) ($p<0.001$). Average grip strength fatigue was 13.1 ± 11.6% for the group and was not significantly different between males (13.6 ± 13.0%) and females (12.1 ± 8.3%). Interestingly there was no correlation between grip fatigue and total climbing time ($R=0.105$, $p=0.257$).

Exclusive Bouldering

Session durations were also examined comparing those who exclusively participated in bouldering versus those who participated in other types of climbing. Those who participated in bouldering recorded shorter average sessions lasting 64.8 ± 21.1 minutes compared to subjects participating in other types of climbing (97.9 ± 29.8 minutes; $p<0.001$). Subjects that bouldered exclusively spent significantly less time (29.7 ± 17.6 min, 44.8 ± 22.2%) than the rest of the group (52.5 ± 25.5 min, 54.8 ± 21.6%.) with heart rates below the ranges set for moderate intensity physical activity ($p<0.001$, $p=0.049$).

When bouldering was compared to the rest of the group mean grip strength was significantly greater in those who exclusively participated in bouldering (54.3 ± 14.8 kg) compared to climbers who did not (47.4 ± 11.8 kg) ($p=0.012$). Fatigue was 11.4 ± 13.4% for exclusive bouldering and 13.4 ± 11.0% for the rest of the climbers. SMR was significantly higher in the subset of climbers who exclusively participated in bouldering (0.76 ± 0.19) compared to those who did not (0.68 ± 0.15) ($p=0.021$).

DISCUSSION

Despite the fact that rock climbing is increasing in popularity annually and the number of indoor climbing facilities is on the rise, little is known about the cardiovascular and strength requirements of recreational indoor rock climbing. To examine the exercise intensity, session duration, and forearm muscle strength characteristics a field study was conducted at two local indoor climbing facilities (Mesa Rim Climbing Centers). During this study heart rate, duration, activity type, body composition, and forearm grip strength were measured in one hundred and fourteen adult recreational indoor climbers. Results from this study demonstrate for the first time that recreational indoor climbers have average heart rates of 122.3 ±14.5 bpm (64.9 ± 7.8%) across their climbing sessions. Additionally, climbing session durations in this study were 90.6 ± 31.3 minutes. During these sessions, climbers spent 21.8 ± 9.8 (24.1 ± 7.1%) of their time actively climbing and 68.9 ± 24.4 (76.0% ± 7.1%) of time participating in non-climbing activities. Heart rate responses from this study suggest that over 47% of the climbing session is spent with heart rates associated with moderate to vigorous exercise intensities, even though a substantial amount of the climbing session (76%) is spent participating in non-climbing activities. In addition to cardiovascular responses and session durations, this study found that grip SMR was 0.71 ± 0.14 and average grip fatigue was 13.1 ± 11.6% for the whole group.

Research literature on indoor rock climbing is limited and focuses primarily on advanced and elite climbers. This lack of focus on recreational climbers has caused there to be a scarcity of information regarding the potential health benefits associated with recreational indoor rock climbing. Past research in experienced and elite climbers reported that outdoor climbing may require a large amount of a persons' peak oxygen uptake and could elicit positive adaptations in aerobic fitness (Booth et al., 1999; Watts & Drobish, 1998). In addition, heart rates during climbing have been reported to range between 73-89% of age predicted maximum (Billat et al., 1995; Booth et al., 1999; Giles et al., 2006; La Torre et al., 2009; Mermier et al., 1997). The current study is the first to characterize heart rate responses in recreational climbers utilizing a large sample size. Data showed that during a typical climbing session, recreational indoor climbers achieve mean heart rates equivalent to 64.9 ± 7.8% of their age predicted maximum over the course of a typical climbing session. However, it is important to note that while actively engaged in climbing, average heart rate increased to 77.0 ± 10.0% of age predicted maximum. This finding suggests that recreational indoor rock climbers achieve average heart rates similar to those reported in advanced or elite climbers while actively climbing.

The CDC and ACSM guidelines focus both on exercise intensity and time spent per week participating in physical activity. Therefore, in the current study session and activity durations of indoor recreational rock climbers was measured. Climbers in the current study recorded session durations of 90.6 ± 31.3 minutes. Of those sessions 24.1 ± 7.1% of their time was spent actively engaging in climbing and 76.0 ± 7.1% was spent participating in other non-climbing activities such as belaying a partner, warming up, and rest. Interestingly, subjects still maintained an average heart rate of 122.3 ± 14.5 bpm or 64.9 ± 7.8% of age predicted maximum, even though only a small portion of their sessions was spent actively climbing. When heart rate and duration data is taken together, the data show that over 48% of the climbing session was spent at a heart rate above 64% of age predicted maximum. Data suggested that subjects' sessions contributed over 20 minutes to the weekly recommendations for moderate intensity physical activity (64-76% max HR), and more than 23 minutes toward vigorous intensity physical activity (76-96%) or higher (American College of Sports Medicine, 2013; Centers for Disease Control and Prevention, 2016). Given that subjects in the current study reported climbing approximately three times per week, one can speculate that participating in recreational climbing contributed to 60 and 69 minutes of moderate and vigorous intensity exercise per week, respectively.

Further analysis comparing those who exclusively participated in bouldering with those who did not revealed that the bouldering group had shorter session durations (64.8 ± 24.4 minutes) and spent less time with heart rates considered to be below moderate intensity physical activity (29.7 ±17.6 minutes) than other climbers. This resulted in a greater percentage of their time (55%) contributing towards the national recommendations. These findings suggest that exclusively participating in bouldering may be more efficient at eliciting cardiovascular health benefits than other types of climbing.

It has been documented that a low body fat percentage plays a role in rock climbing (Watts et al., 1993). The current study found that body fat percentages were higher than most of the previous research on elite climbers (males 4 – 9%, female: 14 -16%) at around 13% for males and 22% for females (Mermier et al., 2000; Mermier et al., 1997; Watts, 2004; Watts et al., 1993). Even though body fat percentages in the current study were higher than those reported in elite climbers, values still fell into ranges considered excellent for males and fair for females (American College of Sports Medicine, 2013). The higher body fat percentages found could be explained by the fact that recreational climbers were used with a minimum of only 6 months of experience which most likely do not train at the level of an elite or competitive climber.

Lower body fat percentages in climbers are beneficial for obtaining higher strength to mass ratios shown to be important for climbing (Watts, 2004; Watts et al., 1993). Strength to mass ratio in regards to grip strength for climbers in the current study was similar to what has been seen in the past (male: 0.65-0.78, female: 0.49-0.75) at 0.75 for males and 0.63 for females (Giles et al., 2006; Mermier et al., 2000; Watts, 2004; Watts et al., 1993). Grip endurance is another important aspect to climbing and one that is largely overlooked in studies and has not been investigated over the course of a climbing session (Watts, 2004). Results from the current study suggest that male and female recreational climbers have a reduction in grip strength across a climbing session of 13.6% and 12.1%, respectively. Additionally, the current data demonstrates subjects that exclusively bouldered had higher absolute grip strength and SMR, but no difference in fatigue when compared to other climbers. Similar results have been seen for absolute grip strength and SMR, but previous research also showed higher endurance in those who participate in bouldering (Fryer et al., 2017). Interestingly, the absence of a correlation between grip fatigue and climbing duration suggests that grip fatigues of approximately 13% may be the limiting factor in climbing duration.

A limitation to this study was that climbers participated in multiple activities during their climbing session. This study was observational by design and did not include any intervention, therefore climbers were able to participate in any or all of the activities observed. While a subset of climbers who exclusively bouldered were identified and analyzed, the absence of groups of exclusive top rope and exclusive lead climbing groups made it inappropriate to statistically determine differences between the types of climbing. Additionally, testing was performed during the busier times at the climbing facilities in order to increase subject recruitment. The increased numbers of members in the climbing facilities at these times may have influenced rest times. A limitation to grip strength testing was the learning aspect to the test causing subjects to record higher grip strengths post climbing compared to pre climbing. Lastly the inability to measure VO_2 limits the ability to interpret HR data and estimate cardiovascular demands. Heart rates may have been elevated due to the use of repetitive isometric contractions which may cause a disproportionate rise in HR compared to VO_2 seen in climbers (Limonta et al., 2018; Mermier et al., 1997; Sheel, 2004).

In conclusion, the results of this study support that recreational indoor rock climbers do achieve heart rates that fall within the ranges set forth by the CDC and ACSM for moderate and vigorous intensity exercise. These heart rates are sustained for a large enough portion of the climbing session to make a substantial contribution to the weekly recommendations known to elicit cardiovascular health benefits. Bouldering may be more efficient at eliciting the cardiovascular responses associated with these health benefits. Additionally, the results suggest that body fat percentages are higher in recreational climbers compared to those reported in elite climbers, whereas grip strength to mass ratios in the current study were similar to those previously reported in elite climbers. Lastly the results from the current study suggest that forearm muscle fatigue may limit climbing durations in recreational climbers .

PRACTICAL APPLICATIONS

This information may be useful to athletes and coaches interested in training programs designed to optimize climbing performance. When training outside of a climbing facility, similar intensities and durations should be considered to mimic climbing. The incorporation of interval training that simulates the periods of higher heart rates with intermittent periods of rest could be useful to prepare a climber for the cardiovascular demands of the sport. Training programs may also want to incorporate exercise to enhance endurance in the muscles of the forearm to decrease the rate of fatigue in climbers. Focusing on enhancing cardiovascular performance and decreasing fatigue rates of the muscles in the forearm could lead to increased performance during climbing. The data from this study can also help indoor rock-climbing facility owners and operators design their facilities. Session and activity durations can be used to develop climbing facilities with the appropriate amount of top rope, lead, and boulder routes throughout the facility. Developers should also consider providing enough space for climbers who are resting which will not interfere with those actively climbing. Alternatively providing enough climbing routes may be an option to reduce the rest periods seen in recreational climbers

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