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ORIGINAL ARTICLE

Flexibility and mobility parameters in climbers and non-climbers

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ABSTRACT

Purpose: In recent years, climbing has become increasingly popular and now has more enthusiasts and research interest than ever before. However, no study has yet considered the relationships between the functional mobility of the upper and lower limbs, climbing experience, climbing-specific hip mobility, and muscle strength. The purpose of this study was to determine whether functional mobility (measured using shoulder mobility and active straight leg raise tests) or climbing-specific hip mobility (measured using an adapted Grant foot raise test [hip flexion] and lateral foot reach test [hip abduction and external rotation determines climbing skills. Methods: A total of 59 volunteer climbers in 3 groups (elite climbers, intermediate climbers, and non-climbers) were assessed according to anthropometry, muscle strength, functional mobility, and hip mobility. Results: Elite climbers performed significantly better than intermediate climbers and non-climbers in tests of the external mobility of the left shoulder (p = .043; η^2 = 0.112) and in the adapted Grant foot raise test (p = .023; η^2 = 0.126). Conclusions: Elite climbers have greater hip mobility than intermediate climbers and non-climbers. Functional shoulder mobility, especially external rotation, may play a role in effective climbing.
Keywords: Technology, Innovation, Flexibility, Climbing, Hip mobility.

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INTRODUCTION

The body of research relating to indoor and outdoor climbing has increased dramatically in recent decades (Mermier et al., 2000) as the sport has gained popularity (Ozimek et al., 2016a). The number of indoor climbing gyms continues to increase, as does the number of people involved in climbing, both recreationally and competitively (Deyhle et al., 2015).

Despite improvements in traditional climbing, the increased number of climbers (Grant et al., 1996), and the growing research in this area (Mermier et al., 2000), scientific data on the subject remains scarce (Fryer et al., 2017; Giles et al., 2006). Much of the scientific literature focuses on injuries and their prevention (Hoge et al., 2010; Mermier et al., 2000). In addition, the literature offers some debate and some conflicting evidence regarding the impacts of physiological and anthropometric factors on climbing performance (Mermier et al., 2000; Watts, 2004).

To predict a climber's performance, researchers assess their physiological workload, how they respond to short-term fatigue and psychological demands (Magiera et al., 2019), their anthropometric characteristics, their muscular strength, their endurance, and the flexibility of their legs and arms (Saul et al., 2019; Watts, 2004). Many tests have been designed to assess climbers' muscle strength, the most commonly used being the handgrip and/or finger strength test (Grant et al., 1996, 2001; Mermier et al., 2000; Ozimek et al., 2016; Sheel, 2004; Watts, 2004). However, when handgrip strength is expressed relative to body mass ratio (SBMR), climbers' scores tend to be more accurate (Watts et al., 1993).

Handgrip strength is used not only to estimate overall muscle strength but also to predict health-related prognoses (Sasaki et al., 2007). In conjunction with finger grip strength, upper-limb power, and endurance, it accounts for 46% of the training components in climbing, while anthropometrics explains only 4% of all variance (Laffaye et al., 2016). With that being said, a recent systematic review suggests that, alongside handgrip strength, low skinfold thickness and body fat, as well as high forearm volume, are all anthropometric traits of a successful climber (Saul et al., 2019).

Among climbers, flexibility is often assessed through range of motion (ROM) (Magiera & Ryguła, 2007; Mermier et al., 2000; Wall et al., 2004) and indirect assessments such as the sit-and-reach test (Draper et al., 2009; Grant et al., 1996, 2001), the leg span test (Grant et al., 1996, 2001) and the foot raise (Draper et al., 2009; Grant et al., 1996, 2001). Mermier et al. (Mermier et al., 2000) show that in climbing performance, variations in the squared semi-partial correlations between the training components, anthropometry, and flexibility are 58.9%, 0.3%, and 1.8%, respectively. This suggests that training components are the only significant predictor of climbing performance, while anthropometry and flexibility contribute little to a climber's overall ability. Additional research (Sheel, 2004) concludes the same and seems to support previous findings (Mermier et al., 2000). Flexibility is not necessarily a determinant of climbing ability (Giles et al., 2006). Nonetheless, Draper et al. (Giles et al., 2006) determined that climbing-specific hip flexion—assessed by the Grant foot raise test—and hip abduction and external rotation—assessed by the lateral foot reach test—should be addressed in any training or rehabilitation program (Draper et al., 2009). On this basis, these authors (Draper et al., 2009) have developed an adapted Grant's foot raise test to address climbing-specific hip flexion. The importance of hip joint mobility—in particular, hip abduction—in rock climbing performance is confirmed by a recent review paper (Michail Lubomirov, 2014), which contrasts with findings related to the ROM of the hip and leg, which do not determine the contestant development performance of climbers (Magiera & Ryguła, 2007).

Rock climbing puts intense demands on the soft tissues surrounding the glenohumeral joint, causing climbers to demonstrate less mobility in scapular upward rotation and to have significantly less mobility in this plane than non-climbers (Roseborrough & Lebec, 2007). Asymmetry in reach skills can also be considered a negative determinant factor in climbing (Čular et al., 2018), with many sport asymmetries being a consequence of limb dominance (Maloney, 2019). Training interventions can reduce sport asymmetries and improve performance, though, further research is needed to fully understand and determine dependencies (Maloney, 2019).

Although previous studies have analysed many of these characteristics in climbers, (Draper et al., 2009; Grant et al., 1996, 2001; Mermier et al., 2000; Watts et al., 1993), to the best of our knowledge, no study has considered functional mobility tests of the upper and lower limbs. Functional mobility exists on the spectrum of functional movement—an indicator of movement proficiency (O'Brien et al., 2017). Mobility is the ability to integrate joint ROM without any restrictions on muscle length, strength, or motor control (Behm, 2019). Regarding ROM competence, the functional movement screen (FMS) is one of the most commonly used screening systems; it provides a clinically interpretable measure of movement quality (Kraus et al., 2014; Marques et al., 2017). The purpose of the FMS is to assess functional movement patterns, thereby creating a functional movement baseline against which subsequent movements can be rated and ranked (Cook, Burton, Hoogenboom, et al., 2014).

On this basis, our study considered the functional mobility of the upper and lower limbs, climbing experience, climbing-specific hip mobility, and muscle strength. Our goal was to compare the functional mobilities, climbing-specific hip mobilities (using the lateral foot reach and adapted Grant foot raise tests), handgrip strengths, and strength-to-body-mass ratios of climbers and non-climbers—with the former divided based on skill level, as either "*intermediate*" and "*elite*." We hypothesized that the elite climbers would perform better than the intermediate climbers and non-climbers in tests of hip mobility, handgrip strength, and strength-to-body-mass ratio.

METHODS

A cross-sectional design was used 1) to analyse the variance of functional mobility, ROM, climbing-specific hip mobility and handgrip strength between groups (elite climbers, intermediate climbers, and non-climbers); and 2) to analyse which test best characterized the elite climbers, intermediate climbers, and non-climbers.

Participants

A total of 59 volunteers (23.7% female and 76.3% male) were evaluated for anthropometry, muscle strength, functional mobility, and hip mobility. The volunteers were then divided into three groups: elite climbers (4 females; n = 17), intermediate climbers (6 females; n = 28), and non-climbers (3 women, n = 14). The proportion of female participants was similar for all groups (22.1%). Participants ranged from 12 to 46 years of age, with an average age of 25.

The tests were conducted in two phases. The first phase was carried out with students and teachers at the School of Sports and Leisure in Melgaço, while the second phase took place during the seniors' national boulder climbing competition in Soure, Coimbra. All subjects—and the parents of those under 18 years of age—received a clear explanation of the study that included information about the risks and benefits of participation. Prior to testing, each participant provided written informed consent according to the Declaration of Helsinki, including consent to be video-recorded for further analysis.

All participants were involved in regular physical activity. When performing the mobility tests, the participants were excluded if: in the presence of pain; unable to complete the movement pattern; or unable to assume the position to perform the movement. Those with no regular practice in climbing were categorized as non-climbers, while those with experience were classified as either elite or intermediate. It was not possible to categorize the climbers based on the International Rock Climbing Research Association's guidelines (Draper et al., 2015), as no universal scale are provided. Thus, the elite group consisted of finalists from all national competitions in the subsequent year, and all remaining climbers were considered intermediate.

Anthropometrics

Bodyweight was measured using a scale (SECA 760, Germany). Subjects were instructed to remove their shoes prior to stepping on the scale platform. The measurement was recorded in kilograms (to the nearest 0.5 kg). Height was measured using a portable stadiometer (SECA 217, Germany). Subjects once again removed their shoes and assumed an anthropometric position on the smooth surface of the stadiometer, with their heels together and their weight distributed evenly across both feet. The head was oriented according to the Frankfurt plain. Testers assisted subjects as needed by applying slight pressure to correct the curvature of the column and then encouraging subjects to take a deep breath. The stem of the stadiometer was compressed on the vertex, and the measurements were taken in centimeters (to the nearest 0.1 cm).

Mobility

The functional movement screen (FMS) (Frost et al., 2012)—a battery of seven qualitative tests that evaluate and classify functional mobility and postural stability without locomotion (Butler, 2010)—was selected. From the seven tests, and considering climbing abilities, we selected two (shoulder mobility and active straight leg raise) for analysis.

The shoulder mobility test requires scapular mobility and thoracic spine extension. It assesses the bilateral and reciprocal ROM in the shoulder, combining internal rotation with the abduction of one shoulder and external rotation with the abduction of the other shoulder (Cook, Burton, Hoogenboom, et al., 2014; Cook et al., 2006). Meanwhile, the active straight leg raise test requires the participant to disassociate the lower extremities from the trunk while maintaining stability in the torso. It assesses active hamstring and gastro-soleus flexibility with a stable pelvis and core, as well as the active extension of the opposite leg (Cook, Burton, Hoogenboom, et al., 2014; Cook et al., 2006).

Three repetitions of each screening test were completed and filmed with a video camera (GC-PX100, JVC, Kenwood Corporation, Japan) for further analysis. The best-performed repetition was scored. For each pattern, a score from 0 to 3 was assigned. A score of 0 indicated that the subject experienced pain somewhere in the body. A score of 1 indicated that the participant was unable to complete the movement pattern or assume the position needed to perform the movement. A score of 2 indicated that the participant was able to complete the movement but had to compensate in some way to do so. Finally, a score of 3 indicated that the participant performed the movement correctly without any compensation and in compliance with the standard movement expectations associated with the test (Cook, Burton, & Hoogenboom, 2014). Approximately 10 seconds of rest was provided between trials, and one minute was given between tests. Subjects always returned to the starting position between attempts. Each side of the body was assessed unilaterally so that asymmetries could be detected.

Shoulder mobility

According to Cook et al. (Cook, Burton, Hoogenboom, et al., 2014; Cook et al., 2006), the tester must first determine hand length by measuring the distance from the distal wrist crease to the tip of the third digit. The subject is then instructed to make a fist with each hand, placing the thumb inside the fist. They are asked to stand and raise one arm above their head, then to bend their elbow, let the first rest on the back of the neck, and then slide it down the back and between the shoulder blades. With the other arm, they then reach towards the back, sliding the first hand down and the second hand up to try and touch both fists together. During the test, both hands should remain in fists, and the fists should be placed on the back in one smooth motion. Once the action is completed, the tester measures the distance between the two closest bony prominences. The test is performed as many as three times bilaterally.

Video of the testing was analysed using the freeware motion-analysis software Kinovea (version 0.8.15, available for download at http://www.kinovea.org). Angulation in internal and external rotation was analyzed while considering the olecranon as the vertex, the middle finger in on the extremities and the acromion in the other extremity.

Active straight leg raise

For this test, the subject assumes a relaxed supine position with the arms in anatomical position, the legs on a towel about 4 centimeters in height, and the head flat on the floor. The tester identifies the midpoint between the anterior superior iliac spine and the midpoint of the patella of the leg on the floor. Then, the subject is instructed to slowly lift the test leg with a dorsiflexed ankle and an extended knee. The knee of the lower leg must remain in contact with the ground, with the toes pointed upward. The head must also remain in contact with the floor. Once the end position is achieved, the tester notes the position of the upward ankle relative to the lower leg and verifies that the latter has maintained a neutral position (i.e., no hip external rotation has occurred). The malleolus helps to identify the score of the test leg. The test is performed three times bilaterally (Cook, Burton, Hoogenboom, et al., 2014; Cook et al., 2006).

Video of the testing was analysed using the freeware motion-analysis software Kinovea (version 0.8.15, available for download at http://www.kinovea.org). Angulation was analysed while considering the anterior superior spine as the vertex, the malleolus on one the extremities and a parallel line within the floor in the other extremity.

Climbing-specific hip mobility

Hip mobility was evaluated using an adapted Grant foot raise test (for hip flexion) and the lateral foot reach test (for hip abduction and external rotation).

Adapted grant foot raise

The adapted Grant foot raise test builds upon the methods described in previous research (Draper et al., 2009; Grant et al., 1996). The objective of this test is to place the foot at maximum hip flexion on the wall directly in front of the climber. In this study, lateral placement of the foot was permitted (Draper et al., 2009) in order to better simulate a climbing movement.

During testing, the subject stands facing a wall with their toes touching a line. The line, in this case, was placed 23 centimeters from the wall. Both of the subject's hands are placed flat on the wall with the fingers pointing upwards at shoulder height. The subject then raises their right foot directly underneath their right hand (guided by a tape measure and adhesive tape) to a maximum hip flexion position. A plantar flexion of the left ankle is permitted to vertically extend the body's position. In climbing, the hands and feet are used in alternation as the climber progresses vertically. During this test was allowed the placement of the right hand next to the meter tape and lifting it so that those who had more capability could reach. The test was performed three times, with the tester measuring the distance from the top of the participant's right foot to the floor for each trial. A few subjects raised their feet as high as or higher than their hands, having been permitted to move their hands slightly to the side.

Lateral foot reach

Draper et al. (2009) developed the lateral foot reach as a climbing-specific measure of hip abduction and external rotation. When performing this test, both of the subject's hands are placed on the right side of a campus rung that is located centrally on a test apparatus and set at the subject's height above the left foothold. The left foot moves to the foothold. Then, the test is completed when the right foot (guided by a tape measure) reaches maximal hip abduction and external rotation horizontally. The left foot and both hands must remain in contact with their corresponding holds throughout the movement. The measurement is taken from the outside of the left foothold to the outside of the right foot.

In the absence of a campus rung and test apparatus, the test was performed on a conventional climbing wall. Because the set-up could not be adjusted for each subject, the rung was maintained at a height of 175 centimeters throughout. The test used the same two holds with the same distance between them on each of the two evaluation days—one wide hold for the hands and one narrow hold for the left foot. Both hands were placed on the right side of a large climbing hold, located centrally above the left foothold.

Handgrip strength

Handgrip strength was assessed using a hand dynamometer with an adjustable grip (SH5001, SAEHAN Corporation) and recorded in kilograms (kg). For each hand, the subject was seated with their shoulder adducted and neutrally rotated, their elbow flexed at 90°, their forearm in a neutral position, and their wrist between 0° and 30° dorsiflexion and between 0° and 15° ulnar deviation (Mullerpatan et al., 2013).

The subject was then instructed and verbally encouraged to squeeze the handgrip as hard as they could. Three trials were completed for each hand, and the highest score for each hand was recorded for further analysis. The strength-to-body-mass ratio (SBMR) was calculated by dividing grip strength by body mass.

Statistical analysis

Descriptive statistics (including an average and a 95% confidence interval for lower and upper limits) were calculated. Differences among the three groups (elite climbers, intermediate climbers, and non-climbers) were investigated for each of the tests in the battery using one-way ANOVA. Assumptions about the normality and homogeneity of the sample were also tested. Eta squared (η^2) tested the effect size (ES) of the inferential analysis, then Ferguson's classification was applied to the ES values (Ferguson, 2009), categorizing each as *no effect* (ES < 0.04), *minimum effect* (0.04 < ES < 0.25), *moderate effect* (0.25 < ES < 0.64), or *strong effect* (ES > 0.64). All statistical analyses were completed using SPSS (version 23.0.0.0 for MAC, IBM, USA) for a $p < .05$.

RESULTS

Significant differences were found between groups (elite climbers, intermediate climbers and non-climbers) in weight ($p = .004$; $\eta^2 = 0.187$, *minimum effect*). No significant differences were found in height ($p = .064$; $\eta^2 = 0.094$, *minimum effect*) [Table 1].

Significant differences were found between groups in shoulder mobility (SM) left external rotation ($p = .043$; $\eta^2 = 0.112$, *minimum effect*). No significant differences were found in SM right ($p = .452$; $\eta^2 = 0.029$, *no effect*), SM left ($p = .247$; $\eta^2 = 0.050$, *minimum effect*), SM asymmetry ($p = .223$; $\eta^2 = 0.054$, *minimum effect*), SM right internal rotation (p = .794; η^2 = 0.008, *no effect*), SM right external rotation (p = .056; η^2 = 0.103, *minimum effect*), or SM left internal rotation (p = .313; η^2 = 0.042, *minimum effect*) [Table 2].

Table 1. Sample description (mean and 95%CI).

	Elite Climbers (N = 17)	**Intermediate Climbers (N = 28)**	**Non-climbers (N = 14)**
Age (years)	22.41 [18.48-26.35]	26.54 [23.47-29.60]	23.36 [19.02-27.69]
Weight (kg)	57.18[b] [51.62-62.73]	69.21[a] [64.89-73.54]	66.79[c] [60.67-72.91]
Height (cm)	166.18 [161.91-170.45]	172.33 [169.01-175.66]	172.06 [167.36-176.77]

Note. Significant different comparing to elite climbers[a]; intermediate climbers[b]; and non-climbers[c] at p < .05; kg – kilograms; cm centimetres.

Table 2. Shoulder mobility (mean and 95%CI) specifications.

	Elite Climbers (N = 17)	**Intermediate Climbers (N = 28)**	**Non-climbers (N = 14)**
SM right (AU)	2.25 [1.80-2.70]	1.96 [1.62-2.31]	1.86 [1.38-2.34]
SM left (AU)	2.06 [1.62-2.51]	1.59 [1.25-1.93]	1.71 [1.24-2.19]
SM asymmetry (AU)	1.38 [1.14-1.61]	1.41 [1.23-1.59]	1.14 [0.89-1.40]
SM right internal (º)	56.44 [49.68-63.20]	59.07 [53.87-64.28]	56.93 [49.70-64.16]
SM right external (º)	35.81 [31.30-40.33]	42.26 [38.79-45.73]	37.08 [32.07-42.08]
SM left internal (º)	56.38 [49.95-62.80]	58.85 [53.91-63.80]	52.36 [45.49-59.22]
SM left external (º)	35.94[b] [30.62-41.26]	44.33[a] [40.24-48.43]	39.15[c] [33.25-45.06]

Note. Significant different comparing to elite climbers[a]; intermediate climbers[b]; and non-climbers[c] at p < .05; SM - shoulder mobility; AU - arbitrary unit; º - degrees.

Table 3. Active straight leg raise (mean and 95%CI) specifications.

	Elite Climbers (N = 17)	**Intermediate Climbers (N = 28)**	**Non-climbers (N = 14)**
ASLR right (AU)	2.75 [2.51-3.00]	2.56 [2.37-2.74]	2.64 [2.38-2.91]
ASLR left (AU)	2.67 [2.39-2.99]	2.48 [2.25-2.71]	2.50 [2.18-2.82]
ASLR asymmetry (AU)	1.06 [0.88-1.25]	1.15 [1.01-1.29]	1.29 [1.09-1.48]
ASLR right (º)	83.06 [77.18-88.95]	77.07 [72.54-81.61]	81.64 [75.35-87.94]
ASLR left (º)	82.31 [75.29-89.34]	76.15 [70.74-81.56]	79.79 [72.28-87.30]
ASLR asymmetry (º)	2.13 [1.45-2.80]	1.59 [1.07-2.11]	1.50 [0.78-2.22]

Note. Significant different comparing to elite climbers[a]; intermediate climbers[b]; and non-climbers[c] at p < .05; ASLR - active straight leg raise; AU - arbitrary unit; º - degrees.

Table 4. Adapted grant foot raise, lateral foot reach, hand grip and strength to body mass ratio (mean and 95%CI) specifications.

	Elite Climbers (N = 17)	**Intermediate Climbers (N = 28)**	**Non-climbers (N = 14)**
AGFR (cm)	124.82[c] [118.21-131.44]	118.77[b] [113.61-123.92]	110.89[a] [103.60-118.18]
LFR (cm)	168.41 [160.59-176.23]	171.32 [165.23-177.42]	165.93 [157.31-174.55]
HG right (kg)	30.65 [27.84-33.46]	34.67 [32.44-36.90]	33.07 [29.98-36.17]
HG left (kg)	30.59 [27.80-33.38]	33.78 [31.56-35.99]	31.86 [28.78-34.93]
SBMR right	0.52 [0.48-0.57]	0.52 [0.48-0.55]	0.51 [0.46-0.56]
SBMR left	0.52 [0.47-0.56]	0.50 [0.47-0.53]	0.49 [0.44-0.54]

Note. Significant different comparing to elite climbers[a]; intermediate climbers[b]; and non-climbers[c] at p < .05; AGFR - adapted grant foot raise; LFR - lateral foot reach; HG - hand grip; SBMR - strength to body mass ratio (grip strength/weight); kg – kilograms; cm centimetres.

No significant differences were found between groups in active straight leg raise (ASLR) right (p = .454; η^2 = 0.029, *no effect*), ASLR left (p = .534; η^2 = 0.023, *no effect*), ASLR asymmetry (p = .252; η^2 = 0.050, *minimum* *effect*), ASLR right (º) (p = .229; η^2 = 0.053, *minimum effect*), ASLR left (º) (p = .367; η^2 = 0.036, *no effect*), or ASLR asymmetry (º) (p = .363; η^2 = 0.037, *no effect*) [Table 3].

Significant differences were found between groups in the adapted Grant foot raise (AGFR) (p = .023; η^2 = 0.126, *minimum effect*). No significant differences were found in the lateral foot reach (LFR) (p = .579; η^2 = 0.019, *no effect*), handgrip (HG) right (p = .089; η^2 = 0.084, *minimum effect*), HG left (p = .195; η^2 = 0.058, *minimum effect*), strength-to-body-mass ratio (SBMR) right (p = .856; η^2 = 0.006, *no effect*), or SBMR left (p = .633; η^2 = 0.017, *no effect*) [Table 4].

DISCUSSION AND CONCLUSIONS

To the best of our knowledge, this study is the first to associate functional mobility testing of the limbs (without locomotion) with climbing experience, climbing-specific hip mobility (using adapted Grant foot raise and lateral foot reach tests), and muscle strength. In elite climbers, the adapted Grant foot raise test proved to be a key identifier of climbing ability (Draper et al., 2009). In our study, this climbing-specific test differed significantly between elite climber, intermediate climber, and non-climber groups, demonstrating that elite climbers have a higher level of hip flexion—on average, higher than the average height—than intermediate climbers and non-climbers do. Non-climbers, meanwhile, have an average hip abduction of less than the average height, hypotactically uncovering their lack of hip mobility and climbing-specific flexibility. In the lateral foot reach test, no statistically significant differences were observed. This might be related to unavoidable equipment adaptations, as it was not possible to adjust the rung according to standard specifications (Draper et al., 2009); it was instead maintained at a height of 175 centimeters.

The handgrip test also showed no significant differences between groups; though, the intermediate climber group displayed a level of force minimally superior to the other groups. This observation may indicate an attempt to compensate for a lack of hip mobility, or it may relate to overall higher body mass among the intermediate climber group. Along the same lines, the strength-to-body-mass ratio also showed no significant differences. Elite climbers presented a ratio similar to the other groups' in the right-hand measurement and minimally superior in the left-hand measurement. These results are consistent with other research (Watts et al., 1993), though at a different magnitude.

The functional mobility tests revealed only one significant difference—specifically, in the external rotation of the left shoulder. No other significant differences were identified in the SM or ASLR tests. This finding may be explained by the elite climbers' use of their upper limbs—combined with complex vertical and lateral movements and position changes—to support body mass (Morrison & Schoffl, 2007). In contrast, the intermediate climbers fall into a compensatory pattern that necessitates, on average, greater handgrip strength and reduced shoulder mobility (particularly, external rotation motion on the left side). The interdependencies of internal and external rotations during the SM test could be affected by sport asymmetries. Although many sport asymmetries are a consequence of limb dominance (Maloney, 2019), asymmetry in climbing reach skills can be considered a negative determinant factor (Čular et al., 2018). For a climber to achieve an efficient upward rotation of the scapula, their serratus anterior and lower trapezius must have an optimum length-tension relationship (Roseborrough & Lebec, 2007).

As discussed, there remains some debate and conflicting evidence in the climbing literature as to the impacts of physiological and anthropometric factors on climbing performance (Mermier et al., 2000; Watts, 2004), and few recent studies have been conducted on the subject. Further research is needed to assess functional mobility among climbers, as well as its implications for climbing performance. Nonetheless, the evidence shows that it is essential for climbers to develop strength, adequate joint ROM, and functional mobility in order to sustain appropriate posture (Tozetto et al., 2012) and to carry out a variety of daily activities (Benetti et al., 2005).

This research has some limitations, including a lack of differentiation between genders, and the absence of a universal climbing scale on which to measure all subjects consistently. Despite this, efforts were made to ensure a consistent proportion of female subjects in each of the groups, and the criteria used to distinguish elite and intermediate athletes met the minimum standards of the International Rock Climbing Research Association (Draper et al., 2015) (ultimately, the elite group consisted of finalists from national competitions). In addition, the study's cross-sectional design made it impossible to generalize the results. Likewise, the use of a functional mobility test—simultaneously a strength and a limitation—made it challenging to compare the present study to previous studies with similar methodologies.

CONCLUSIONS

Elite climbers had better hip flexion and hip abduction (based on the adapted Grant foot raise test) than intermediate climbers and non-climbers. Functional shoulder mobility, especially external rotation, may play a role in climbing skills. The results of this study suggest that intermediate climbers could benefit from additional training to enhance hip mobility.

AUTHOR CONTRIBUTIONS

Conceptualization: BT, NC and BS; Methodology: BT and BS; Data Analysis: BT, NC and BS; Writing BT and BS; Writing - Review & Editing: BT, NC and BS; Project Supervision: BS.

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REFERENCES

Behm, D. G. (2019). The Science and Physiology of Flexibility and Stretching - Implications and Applications in Sport Performance and Health (1o Edition). Routledge. https://doi.org/10.4324/9781315110745-1

Benetti, G., Schneider, P., & Meyer, F. (2005). Sport benefits and the importance of muscle strength trainability in prepubertal volleyball athletes. Revista Brasileira de Cineantropometria e Desempenho Humano, September, 87-93.

Butler, K. I. M. K. B. K. L. B. Aron T. P. P. R. J. (2010). Interrater reliability of the FMS. Strength And Conditioning, 24(2), 479-486. https://doi.org/10.1519/JSC.0b013e3181c09c04

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. N Am J Sports Phys Ther, 1(2), 62-72.

Cook, G., Burton, L., & Hoogenboom, B. (2014). Functional Movement Screening: The Use of Fundamental Movements as an Assessment of Function- Part 2. International Journal of Sports Physical Therapy, 9(4), 549-563. https://doi.org/10.1055/s-0034-1382055

Čular, D., Dhahbi, W., Kolak, I., Dello Iacono, A., Bešlija, T., Laffaye, G., & Padulo, J. (2018). Reliability, Sensitivity, and Minimal Detectable Change of a New Specific Climbing Test for Assessing Asymmetry in Reach Technique. Journal of Strength and Conditioning Research. https://doi.org/10.1519/JSC.0000000000002694

Deyhle, M. R., Hsu, H.-S., Fairfield, T. J., Cadez-Schmidt, T. L., Gurney, B. A., & Mermier, C. M. (2015). Relative Importance of Four Muscle Groups for Indoor Rock Climbing Performance. Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 29(7), 2006-2014. https://doi.org/10.1519/JSC.0000000000000823

Draper, N., Brent, S., Hodgson, C., & Blackwell, G. (2009). Flexibility assessment and the role of flexibility as a determinant of performance in rock climbing. International Journal of Performance Analysis of Sport, 9(June 2014), 67-89. https://doi.org/10.1080/24748668.2009.11868465

Draper, N., Giles, D., Schöffl, V., Konstantin Fuss, F., Watts, P., Wolf, P., Baláš, J., Espana-Romero, V., Blunt Gonzalez, G., Fryer, S., Fanchini, M., Vigouroux, L., Seifert, L., Donath, L., Spoerri, M., Bonetti, K., Phillips, K., Stöcker, U., Bourassa-Moreau, F., … Abreu, E. (2015). Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. Sports Technology, 8(3-4), 88-94. https://doi.org/10.1080/19346182.2015.1107081

Ferguson, C. J. (2009). An Effect Size Primer: A Guide for Clinicians and Researchers. Professional Psychology: Research and Practice, 40(5), 532-538. https://doi.org/10.1037/a0015808

Frost, D. M., Beach, T. A. C., Callaghan, J. P., & McGill, S. M. (2012). Using the Functional Movement Screen to evaluate the effectiveness of training. J Strength Cond Res, 26(6), 1620-1630. https://doi.org/10.1519/JSC.0b013e318234ec59

Fryer, S., Stone, K. J., Sveen, J., Dickson, T., Giles, D., Baláš, J., Stoner, L., Draper, N., Stone, K. J., Sveen, J., Dickson, T., & Giles, D. (2017). Differences in forearm strength , endurance , and hemodynamic kinetics between male boulderers and lead rock climbers. European Journal of Sport Science ISSN:, 17(9), 1177-1183. https://doi.org/10.1080/17461391.2017.1353135

Giles, L. V., Rhodes, E. C., & Taunton, J. E. (2006). The physiology of rock climbing. Sports Medicine, 36(6), 529-545. https://doi.org/10.2165/00007256-200636060-00006

Grant, S., Hasler, T., Davies, C., Aitchison, T. C., & Wilson, J. (2001). A comparison of the anthropometric, strength, endurance and flexibility characteristics of female elite and recreational climbers and non-climbers. Journal of Sports Sciences, 19(7), 499-505. https://doi.org/10.1080/026404101750238953

Grant, S., Hynes, V., Whittaker, A., & Aitchison, T. (1996). Anthropometric , strength , endurance and flexibility characteristics of elite and recreational climbers. Journal of Sports Sciences, 14 (January 1996), 301-309. https://doi.org/10.1080/02640419608727715

Hoge, K. M., Ryan, E. D., Costa, P. B., Herda, T. J., Walter, A. A., Stout, J. R., & Cramer, J. T. (2010). Gender Differences in Musculotendinous Stiffness and Range of Motion After an Acute Bout of Stretching. Journal of Strength and Conditioning Research, 24(10), 2618-2626. https://doi.org/10.1519/JSC.0b013e3181e73974

Kraus, K., Schütz, E., Taylor, Wi. R. W. R., & Doyscher, R. (2014). Efficacy of the functional movement screen: A review. Journal of Strength and Conditioning Research, 28(12), 3571-3584. https://doi.org/10.1519/JSC.0000000000000556

Laffaye, G., Levernier, G., & Collin, J.-M. (2016). Determinant factors in climbing ability: Influence of strength, anthropometry, and neuromuscular fatigue. Scandinavian Journal of Medicine & Science in Sports, 26(10), 1151-1159. https://doi.org/10.1111/sms.12558

Magiera, A., Łukasik, I., Roczniok, R., & Placek, O. (2019). The effects of change in the safety rope protocol, hold size, and rest period on psychophysiological responses in sport rock climbers. Human Movement, 20(2), 34-43. https://doi.org/10.5114/hm.2019.79733

Magiera, A., & Ryguła, I. (2007). Biometric Model and Classification Functions in Sport Climbing. Journal of Human Kinetics, 18, 87-98.

Maloney, S. J. (2019). The Relationship Between Asymmetry and Athletic Performance: A Critical Review. Journal of Strength and Conditioning Research, 33(9), 2579-2593. https://doi.org/10.1519/JSC.0000000000002608

Marques, V. B., Medeiros, T. M., de Souza Stigger, F., Nakamura, F. Y., & Baroni, B. M. (2017). The Functional Movement Screen (FMS) in elite young soccer players between 14 and 20: composite score, individual test scores and asymmetries. International Journal of Sports Physical Therapy, 12(6), 977-985. https://doi.org/10.16603/ijspt20170977

Mermier, C. M., Janot, J. M., Parker, D. L., & Swan, J. G. (2000). Physiological and anthropometric determinants of sport climbing performance. British Journal of Sports Medicine, 34(5), 359-366. https://doi.org/10.1136/bjsm.34.5.359

Michail Lubomirov. (2014). Workload characteristic, performance limiting factors and methods for strength and endurance training in Rock Climbing. Medicina Sportiva, 3(18), 97-106. https://doi.org/10.5604/17342260.1120661

Morrison, A. B., & Schoffl, V. R. (2007). Physiological responses to rock climbing in young climbers. British Journal of Sports Medicine, 41(12), 852-861. https://doi.org/10.1136/bjsm.2007.034827

Mullerpatan, R. P., Karnik, G., & John, R. (2013). Grip and pinch strength: Normative data for healthy Indian adults. Hand Therapy, 18(1), 11-16. https://doi.org/10.1177/1758998313479874

O'Brien, W., Duncan, M., Farmer, O., & Lester, D. (2017). Do Irish Adolescents Have Adequate Functional Movement Skill and Confidence? Journal of Motor Learning and Development. https://doi.org/10.1123/jmld.2016-0067

Ozimek, M., Staszkiewicz, R., Rokowski, R., & Stanula, A. (2016). Analysis of Tests Evaluating Sport Climbers' Strength and Isometric Endurance. Journal of Human Kinetics, 53(1), 249-260. https://doi.org/10.1515/hukin-2016-0027

Roseborrough, A., & Lebec, M. (2007). Differences in static scapular position between rock climbers and a non-rock climber population. North American Journal of Sports Physical Therapy: NAJSPT, 2(1), 44-50.

Sasaki, H., Kasagi, F., Yamada, M., & Fujita, S. (2007). Grip Strength Predicts Cause-Specific Mortality in Middle-Aged and Elderly Persons. The American Journal of Medicine, 120(4), 337-342. https://doi.org/10.1016/j.amjmed.2006.04.018

Saul, D., Steinmetz, G., Lehmann, W., & Schilling, A. F. (2019). Determinants for success in climbing: A systematic review. Journal of Exercise Science and Fitness, 17(3), 91-100. https://doi.org/10.1016/j.jesf.2019.04.002

Sheel, A. W. (2004). Physiology of sport rock climbing. British Journal of Sports Medicine, 38(3), 355-359. https://doi.org/10.1136/bjsm.2003.008169

Tozetto, A. V. B., Milistetd, M., Medeiros, T. E., & Ignachewshi, W. L. (2012). Performance of young athletes on the physical abilities, flexibility, strength and agility. Cinergis, 13(6), 47-54.

Wall, C. B., Starek, J. E., Fleck, S. J., & Byrnes, W. C. (2004). Prediction of indoor climbing performance in women rock climbers. Journal of Strength and Conditioning Research, 18(1), 77-83. https://doi.org/10.1519/1533-4287(2004)018<0077:POICPI>2.0.CO;2

Watts, P. B. (2004). Physiology of difficult rock climbing. In European Journal of Applied Physiology (Vol. 91, Issue 4, pp. 361-372). https://doi.org/10.1007/s00421-003-1036-7

Watts, P. B., Martin, D. T., & Durtschi, S. (1993). Anthropometric profiles of elite male and female competitive sport rock climbers. Journal of Sports Sciences, 11(2), 113-117. https://doi.org/10.1080/02640419308729974

