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# Climbing-specific fitness profile predicts performance in recreational climbers

## *Perfil de condicionamento físico específico para escalada prevê desempenho em escaladores recreativos*

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**Abstract –** Climbing performance is closely associated with finger flexor strength and endurance. Given the growing popularity of climbing, providing coaches with reliable reference values is essential for optimizing training prescriptions for recreational climbers. This study evaluated the isometric strength and endurance of finger flexors in recreational climbers of different ability levels and investigated their relationship with climbing performance. A total of 126 male participants (30 non-climbers, 30 low-grade, 36 intermediate, and 30 advanced) were assessed according to the IRCRA scale. Measurements included maximum hanging time on a 25 mm ledge, hand grip strength, pinch strength, and body composition. Maximum hanging time showed significant differences between groups and a strong correlation with climbing performance (r = 0.72), as did climbing experience (r = 0.70). Relative handgrip and pinch strength (normalized to body mass) **showed moderate** correlations with sport climbing (r = 0.41) and bouldering (r = 0.48). Maximum hanging time emerged as a robust objective marker for distinguishing ability levels and monitoring finger flexor adaptations in recreational climbers.

**Key words:** Hand grip strength; Physical endurance; Pinch strength.

**Resumo –** *O desempenho na escalada está fortemente associado à força e resistência dos flexores dos dedos. Diante do crescente número de praticantes, fornecer aos treinadores valores de referência confiáveis torna-se essencial para otimizar a prescrição de treinamentos voltados a escaladores recreativos. Este estudo avaliou a força e a resistência isométrica dos flexores dos dedos em escaladores recreativos de diferentes níveis de habilidade e investigou sua relação com o desempenho na escalada. Um total de 126 homens (30 não escaladores, 30 de baixo nível, 36 intermediários e 30 avançados) foi avaliado de acordo com a escala da International Rock Climbing Research Association (IRCRA). As variáveis analisadas incluíram o tempo máximo de suspensão em reglete de 25 mm, força de preensão palmar, força de pinça e composição corporal. O tempo máximo de suspensão apresentou diferenças significativas entre os grupos e forte correlação com o desempenho na escalada (r = 0,72), assim como o tempo de experiência em escalada (r = 0,70). Os valores relativos de força de preensão palmar e força de pinça (normalizados pela massa corporal) apresentaram correlações moderadas com o desempenho na escalada esportiva (r = 0,41) e no boulder (r = 0,48). O tempo máximo de suspensão se destacou como um marcador objetivo robusto para diferenciar os níveis de habilidade e monitorar adaptações dos flexores dos dedos em escaladores recreativos.*

**Palavras-chave:** *Força de mão; Resistência física; Força de pinça.*

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# INTRODUCTION

The climbing industry has significantly expanded its business and increased professionalization in recent decades, concurrently due to a growing number of indoor climbing facilities and recreational practitioners[1,2]. The two most common indoor climbing disciplines are Bouldering and Sport Climbing. Bouldering is performed on walls up to 5 meters high and typically involves routes with complex movement sequences. Climbers are challenged by problems that generally require fewer than ten moves, and any falls are safely cushioned by crash pads placed on the ground. In Sport Climbing, the practice is performed on higher walls, thus climbers will be challenged to execute a higher number of movements to reach the top using a safety rope. In both modalities, successful ascent—whether of a bouldering problem or a lead route—requires the climber to progress without any external assistance and without falling. Performance can occur either without prior knowledge, verbal cues, or visual inspection of the route (known as onsight climbing), or after previous practice and attempts (referred to as redpoint climbing, or RP). Climbing performance is typically defined by the highest redpoint grade for which the climber has completed three ascents on three different routes of the same difficulty within the past six months[3]. To standardize performance classification, the International Rock Climbing Research Association (IRCRA) developed a universal scale that aligns local and national grading systems, allowing for the categorization of climbers into five levels: lower-grade, intermediate, advanced, elite, and high-elite[4]. The researchers investigating the predictors of performance in climbing have detailed several essential aspects related to the elite and its differences from non-elite climbers. Elite climbers typically exhibit higher absolute and relative hand strength (i.e., normalized to body mass)[5-7] lower values for anthropometric parameters such as body mass and body fat, and superior finger flexor strength and endurance[8,9]. Non-elite climbers present a wide range of recreational practitioners, such as low-grade, intermediate, and advanced. Previous studies have investigated performance predictors in recreational climbers by grouping different categories in the same group[10,11]. Other studies evaluated only advanced practitioners with experience of around eight years[7,8,12]. As far as we know, few studies investigate trainable variables among low-grade and intermediate[13,14]. As this group represents the most considerable portion of practitioners, it is crucial to design studies to investigate recreational climbers to define distinguishing parameters among them.

In this sense, the amount of research that elucidates physiological descriptors of performance that separate athletes from recreational climbers has yielded coaches and trainers some reference values to prescribe and adjust training goals[14]. Improving climbing grades, Onsight, and redpoint abilities in recreational climbers should also be discussed and supported by sports sciences. Therefore, this study aimed to investigate whether the physical indicators and climbing experience can distinguish recreational climbers in their different performance levels and whether they correlate with their redpoint performance.

# METHODS

## Participants

A total of 126 males (30 non-climbers and 96 recreational climbers, age 31.07 ± 6.81 years, body mass 69.92 ± 10.00 kg, height 1.73 ± 0.07 m) were

verbally invited and agreed to participate in the study. Detailed information describing participants' characteristics is available in Table 1. To be included in the study, all recreational climbers should have been practicing the Sport for at least one year, climbing outdoors, and attending a climbing gym at least once a week. The non-climbers were recruited in the climbing gym in their first class. The participants should have presented no injuries that impaired any sports practice three months before this study. The study received approval from the Ethics Committee of the School of Physical Education and Sport of Ribeirão Preto (São Paulo University, under protocol number 39968120.50000.5659) by the declaration of Helsinki.

## Procedures

All collections were performed between 7 and 10:30 a.m., participants were instructed not to exercise and not to consume alcohol and caffeine 24 hours before the tests. During a single visit, the subjects were interviewed to determine their climbing experience and self-reported performance utilizing the methods mentioned below. Anthropometric measurements, body composition, and hand strength followed this.

## Self-reported climbing performance

The climbers' performance level was determined through self-reported data. Participants were asked to indicate the highest redpoint grade they had successfully climbed within the last three months, with at least three ascents completed on different routes of the same grade, in accordance with Draper et al.[3]. Based on these self-reported grades, climbers were classified according to the IRCRA international scale, which standardizes ability categories by converting regional grading systems into performance bands[4]. In this study, the 96 recreational climbers were distributed into three categories: lower-grade (grades 10–13), intermediate (grades 14–19), and advanced (grades 20–23).

## Anthropometric measurements and body composition

Height was measured using a 2m" portable wall stadiometer with an accuracy of 1 cm (WELMY®, Brazil). The APE index was calculated from an individual's wingspan divided by the height[15]. Body composition (body mass, lean mass %, and body fat %) was assessed using a bioelectrical impedance device (OMRON HBF 514C, Krell Precision Co., Yangzhou, China).

## Hand and pinch strength

Handgrip strength was assessed using a hand dynamometer (Jamar®, B&L Engineering, Santa Ana, USA). The test was performed bilaterally, with participants seated, shoulders adducted, elbows flexed at 90°, and forearms in a horizontal position. The palms faced inward while grasping the dynamometer handle, which was adjusted to fit each participant's hand so that the middle phalanges rested on the inner handle surface[16]. Participants were instructed to apply maximal force for three seconds in each trial, with three attempts performed

per hand, alternating sides and allowing one minute of rest between trials. The mean of the three trials for both hands was recorded in kilogram-force (kgf)[17].

Pinch strength was assessed using a three-point pinch gauge (B&L Engineering, Santa Ana, USA), following the protocol recommended by the American Society of Hand Therapists[18]. The test was conducted with participants seated, shoulders adducted, elbows flexed at 90°, and forearms supported horizontally, with palms facing downward. Force was exerted between the pads of the index and middle fingers and the pad of the thumb (tripod pinch). The testing protocol mirrored that of the handgrip assessment.

### Finger flexors endurance

The endurance of the finger flexor muscles was assessed using the maximum hanging time on a 25 mm edge positioned 2 meters above the ground. Participants were allowed to self-select the grip type—half crimp or open crimp—to maintain their hold on the edge[19,20]. No significant difference in performance time was expected between the half crimp and open crimp grips, as both positions generate comparable flexion forces under combined tendon loading[21]. During the test, individuals were required to maintain shoulder flexion at 180° and full elbow extension while hanging. The test was terminated when the participant could no longer sustain the hold, and time was recorded using a digital chronometer (Casio®, Brazil)[19].

Before testing, participants performed a standardized warm-up, including joint mobilization of the neck, shoulders, arms, wrists, and fingers, followed by two submaximal hangs for neuromuscular activation[20]. Each participant completed two maximal hanging attempts, separated by a five-minute rest period. The longer of the two attempts was used for analysis.

### Statistical analysis

All analyses were conducted using JASP software (Version 0.16.2; Nieuwe Achtergracht 129B, Amsterdam, Netherlands). Data are presented as mean and standard deviation. Statistical significance was set at $p < 0.05$. The Shapiro–Wilk test was applied to assess the normality of data distribution. To compare group means, one-way ANOVA was performed, followed by Tukey's post-hoc test when significant differences were detected. Spearman's rank correlation coefficients were calculated to examine the relationships between climbing performance (sport climbing and bouldering) and the assessed variables.

Two linear regression analyses were conducted to identify predictors of redpoint performance in both sport climbing and bouldering. In the first model, each variable was tested individually (simple linear regression). In the second model, a stepwise multiple regression was performed, incorporating all variables simultaneously to explore the most predictive combinations.

## RESULTS

Descriptive data on body composition, climbing experience, performance, and strength parameters are presented in Table 1. No statistically significant differences were found among the four groups for age, height, or ape index.

**Table 1.** Participant characteristics and differences between groups.

| Groups | Non Climber | Low Grade | Intermediate | Advanced |
|---|---|---|---|---|
| Male (n) | n = 30 | n = 30 | n = 36 | n = 30 |
| **Redpoint performance** | | | | |
| Lead Climbing (IRCRA) | - | 11.9 ± 0.1 | 16.7 ± 1.5[b] | 21.4 ± 1.0b[c] |
| Bouldering (IRCRA) | - | 13.5 ± 1.7 | 17.8 ± 2.0b | 22.1 ± 2.5bc |
| **Experience** | | | | |
| Climbing (years) | - | 2.5 ± 2.3 | 6.9 ± 6.8b | 9.9 ± 4.9b |
| **Body composition** | | | | |
| Body mass (kg) | 74.5 ± 11.6 | 70.9 ± 9.6 | 69.0 ± 9.6 | 65.4 ± 6.8a |
| Body fat (%) | 20.5 ± 5.3 | 15.9 ± 6.1[a] | 14.3 ± 4.3a | 12.5 ± 3.7a |
| Lean mass (%) | 39.3 ± 3.3 | 41.6 ± 4.6 | 41.6 ± 3.9 | 43.52 ± 2.7a |
| **Strength** | | | | |
| Hand strength (Kgf) | 42.1 ± 10.7 | 46.08 ± 8.0 | 49.19 ± 10.5a | 49.65 ± 6.1a |
| Pinch strength (kgf) | 8.65 ± 1.8 | 9.51 ± 1.7 | 10.78 ± 2.1a | 11.07 ± 1.8ab |
| Hand strength/body mass (kgf/kg) | 0.56 ± 0.11 | 0.65 ± 0.10a | 0.71 ± 0.12a | 0.76 ± 0.17ab |
| Pinch strength/body mass (kgf/kg) | 0.11 ± 0.02 | 0.13 ± 0.02a | 0.15 ± 0.02ab | 0.17 ± 0.03ab |
| Maximum hanging time (s) | 6.51 ± 4.2 | 23.23 ± 12.5a | 41.66 ± 12.6ab | 58.77 ± 18.2abc |

**Note.** Data are in mean and standard deviation; Tukey's post-hoc; [a] Shows the group is significantly different ($p < 0.05$) from control group; [b] Shows the group is significantly different ($p < 0.05$) from the low grade; [c] Shows the group is significantly different ($p < 0.05$) from the intermediate.

The highest statistically significant correlation was found between climbing experience and hanging time in Table 2.

**Table 2.** Spearman rank correlations between Sport Climbing and Bouldering redpoint and anthropometry, experience and strength indicators.

| | Sport Climb | | Boulder | |
|---|---|---|---|---|
| | r | *p* | r | *p* |
| **Anthropometrics** | | | | |
| Body mass (kg) | -0.25 | 0.01** | -0.25 | 0.01* |
| Body fat (%) | -0.22 | 0.02* | -0.26 | < .001*** |
| Lean mass (%) | 0.17 | 0.08 | 0.24 | 0.01* |
| **Experience** | | | | |
| Climbing (years) | 0.70 | <.001*** | 0.65 | 0.02* |
| **Strength** | | | | |
| Hand strength (kgf) | 0.21 | 0.03* | 0.29 | <.001*** |
| Pinch strength (kgf) | 0.38 | <.001*** | 0.49 | <.001*** |
| Hand strength/body mass (kgf/kg) | 0.41 | <.001*** | 0.41 | <.001*** |
| Pinch strength/body mass (kgf/kg) | 0.48 | <.001*** | 0.50 | <.001*** |
| Maximum hanging time (s) | 0.72 | <.001*** | 0.71 | <.001*** |

**Note.** Kilograms = (kg), Hand strength/body mass (kg/kg) = Ratio between body mass and hand strength. Pinch strength/body mass (kg/kg) = Ratio between body mass and pinch strength. *** $p < 0.001$, * $p < 0.05$.

The variables with their respective individual contributions to sport climbing and bouldering performance in recreational climbers are shown in Table 3. From the 11 variables included in the stepwise multiple regression, only 2 variables presented significant association performance in sport climbing and bouldering: maximum hanging time of 25 mm and climbing experience.

**Table 3.** Linear regression between Sport Climbing and Bouldering redpoint, anthropometry, experience, and strength indicators.

| | Sport Climb | | | Boulder | | |
|---|---|---|---|---|---|---|
| | $R^2$ | Standard error | *p* | $R^2$ | Standard error | *p* |
| **Anthropometrics** | | | | | | |
| Body mass (kg) | 0.06 | 3.01 | 0.01* | 0.06 | 3.01 | 0.01* |
| Body fat (%) | 0.06 | 1.19 | 0.01* | 1.19 | 1.19 | 0.02* |
| Lean mass (%) | 0.03 | 4.31 | 0.06 | 0.05 | 4.27 | 0.01* |
| **Experience** | | | | | | |
| Climbing (years) | 0.26 | 2.25 | <.001*** | 0.21 | 2.48 | <.001*** |
| **Strength** | | | | | | |
| Hand strength (kgf) | 0.04 | 3.75 | 0.03* | 0.05 | 3.97 | 0.02* |
| Pinch strength (kgf) | 0.13 | 1.99 | <.001*** | 0.14 | 1.98 | <.001*** |
| Hand strength/Body mass (kgf/kg) | 0.17 | 2.19 | <.001*** | 0.22 | 2.13 | <.001*** |
| Pinch strength/Body mass (kgf/kg) | 0.23 | 1.75 | <.001*** | 0.25 | 1.72 | <.001*** |
| Maximum hanging time (s) | 0.50 | 6.34 | <.001*** | 0.52 | 6.62 | <.001*** |

**Note.** Kilograms (kg) and Standard Error (SE). Hand strength/body mass (kgf/kg) = Ratio between body mass and hand strength. Pinch strength/body mass (kgf/kg) = Ratio between body mass and pinch strength. *** $p < 0.001$, * $p < 0.05$.

## DISCUSSION

This study aimed to determine whether physical indicators and climbing experience can distinguish recreational climbers across different performance levels, and to assess the extent to which these parameters correlate with redpoint performance. The results indicate that isometric hand grip endurance and years of climbing experience are strongly associated with higher performance levels among recreational climbers.

Maximum hanging time has previously been reported as a reliable predictor of isometric finger flexor endurance, showing strong correlations with redpoint performance[7,14]. In our study, maximum hanging time significantly differed across all groups, supporting the notion that isometric finger flexor endurance is a critical determinant of climbing performance in recreational athletes. Our findings for intermediate and advanced climbers align with previous studies[6,13], which suggest reference values for endurance as indicative of specific performance levels.

Although earlier investigations have used ledge depths between 6 and 14 mm to assess endurance more sensitively in advanced climbers[8,19], these smaller edges impose greater mechanical constraints, making the test unsuitable for lower-level climbers. This is primarily due to the need to engage less than half of the distal phalanx, placing high demands on the deep finger flexor tendons[21]—a capacity typically observed in elite climbers. In the present study, we opted for a 25 mm ledge, which exceeds half the length of the participants' distal phalanges, thereby promoting greater activation of the flexor digitorum superficialis muscle and making the protocol more appropriate for recreational populations.

In addition to endurance, strength-related parameters also emerged as relevant to performance in this group. Handgrip strength was higher in intermediate and advanced climbers compared to non-climbers; however, no significant differences were observed among the climbing subgroups—a finding consistent with previous literature[11]. Pinch strength, on the other hand, differed significantly between non-climbers, intermediate, and advanced climbers. Advanced climbers demonstrated a 28% greater pinch strength than non-climbers, suggesting that

pinch strength may serve as a promising target for training interventions aimed at improving climbing performance[22].

Despite this, variability in pinch strength assessment protocols across studies complicates direct comparisons[10,11,15,17,23]. Strength-to-body mass ratios have been proposed as more effective discriminators of performance level[12,24]. In our study, both handgrip and pinch strength relative to body mass were significantly higher in climbers compared to non-climbers, and these ratios increased progressively with climbing ability. Specifically, advanced climbers demonstrated a 55% higher pinch strength-to-body mass ratio and a 36% higher handgrip strength-to-body mass ratio compared to non-climbers. These findings suggest that pinch strength relative to body mass may be a more sensitive indicator of climbing ability in recreational athletes.

Moreover, pinch strength, handgrip/body mass, and pinch/body mass ratios all demonstrated moderate correlations with climbing performance and endurance. This reinforces the contribution of pinch strength to climbing proficiency. The stronger association observed for pinch strength, relative to handgrip, may reflect the specific intramuscular coordination required for the three-point pinch test. In this task, the flexor digitorum superficialis stabilizes the middle phalanges of the index and middle fingers, while the thenar muscles maintain flexion of the proximal phalanx of the thumb[16]. These neuromechanical demands may explain the superiority of the three-point pinch test over conventional dynamometry in detecting performance-related adaptations in recreational climbers.

Concerning body composition, lean mass and fat percentage showed only weak correlations with redpoint performance. These findings contrast with those from studies involving elite climbers[7] and suggest that anthropometric characteristics may be less relevant to climbing performance at lower and intermediate levels. For recreational climbers, performance gains appear to depend more on finger flexor endurance and accumulated climbing experience.

The stepwise regression analysis identified finger endurance and years of experience as the primary contributors to performance in both sport climbing and bouldering, accounting for 74% and 72% of the variance, respectively. In the linear regression model, finger flexor endurance alone accounted for approximately 50% of the variance, while relative finger flexor strength explained 17%, and body fat percentage accounted for just 6%. These results differ from those of previous studies[13], likely due to differences in sample composition. Whereas our study focused exclusively on recreational climbers, the referenced work included elite athletes, who typically display greater strength and endurance alongside lower body mass[6].

Experience alone explained 26% of the variance in redpoint performance in our sample, a value consistent with prior findings[13]. Our data suggest that achieving advanced recreational performance levels generally requires 7 to 10 years of regular practice.

In summary, finger flexor endurance and climbing experience are the most relevant predictors of redpoint performance among recreational sport climbers and boulderers. Notably, maximum hanging time performance differed significantly across all performance categories. Additionally, pinch strength demonstrated greater sensitivity than handgrip strength in capturing training-induced adaptations. In contrast, body composition appeared to have limited influence on performance at the recreational level, in contrast to its importance in elite climbing populations[7].

Several limitations should be acknowledged. Comparing findings across studies remains challenging due to a lack of standardization in group classification, equipment used, testing protocols, and data reporting. Although the IRCRA has proposed a standardized framework for classifying climbers[4], it is not yet universally adopted. This heterogeneity complicates inter-study comparisons. Post-hoc analysis of our data also revealed opportunities to enhance methodological precision—for example, by including additional measures such as alternative pinch protocols or forearm circumference—both of which are recommended for future investigations.

## CONCLUSION

We conclude that finger hang endurance is as essential to bouldering as it is for recreational climbing performance. The results of our study suggest that maximum hanging time on a 25 mm ledge differs across all ability levels and can be used as a performance benchmark in sport climbing and Bouldering due to their strong association. If a better diagnosis of the climber is needed, pinch strength relative to body mass is a sensitive measure for both modalities. Therefore, sport climbers and boulder practitioners can benefit from trainable factors, such as finger endurance and pinch strength, to improve their performance.

## COMPLIANCE WITH ETHICAL STANDARDS

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### Data Availability Statement

Research data is only available upon request.

### Ethical approval

Ethical approval for this study was obtained from the Human Research Ethics Committee of the School of Physical Education and Sport of Ribeirão Preto, University of São Paulo (Protocol No. 4.632.264; CAAE: 39968120.5.0000.5659). The study was conducted in accordance with the Declaration of Helsinki.

### Conflict of interest statement

The authors have no conflict of interests to declare.

### Author Contributions

Study conception, data collection, statistical analysis, and manuscript writing: TCPG; methodological design and technical support: AFG, FEP-N, EFP;

critical revision of the content: JE, EFP. All authors approved the final version of the manuscript.

## REFERENCE


1. Batuev M, Robinson L. Organizational evolution and the Olympic Games: the case of sport climbing. Sport Soc 2018;22(10):1674-90. http://doi.org/10.1080/17430437.2018.1440998.
2. Nichols J, Wing D, Bellicini Z, Bates R, Hall D, Hall D, et al. Climbing-specific fitness profiles and determinants of performance in youth rock climbers. J Sports Sci 2018;6:257-67.
3. Draper N, Canalejo JC, Fryer S, Dickson T, Winter D, Ellis G, et al. Reporting climbing grades and grouping categories for rock climbing. Isokinet Exerc Sci 2011;19(4):273-80. http://doi.org/10.3233/IES-2011-0424.
4. Draper N, Giles D, Schöffl V, Fuss FK, Watts PB, Wolf P, et al. Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. Sports Technol 2016;8(3-4):88-94. http://doi.org/10.1080/19346182.2015.1107081.
5. Fryer S, Stoner L, Stone K, Giles D, Sveen J, Garrido I, et al. Forearm muscle oxidative capacity index predicts sport rock-climbing performance. Eur J Appl Physiol 2016;116(8):1479-84. http://doi.org/10.1007/s00421-016-3403-1. PMid:27255506.
6. Ozimek M, Staszkiewicz R, Rokowski R, Stanula A. Analysis of tests evaluating sport climbers' strength and isometric endurance. J Hum Kinet 2016;53(1):249-60. http://doi.org/10.1515/hukin-2016-0027. PMid:28149428.
7. Ozimek M, Rokowski R, Draga P, Ljakh V, Ambroży T, Krawczyk M, et al. The role of physique, strength and endurance in the achievements of elite climbers. PLoS One 2017;12(8):e0182026. http://doi.org/10.1371/journal.pone.0182026. PMid:28771525.
8. Bergua P, Montero-Marin J, Gomez-Bruton A, Casajús JA. Hanging ability in climbing: an approach by finger hangs on adjusted depth edges in advanced and elite sport climbers. Int J Perform Anal Sport 2018;18(3):437-50. http://doi.org/10.1080/24748668.2018.1486115.
9. López-Rivera E, González-Badillo JJ. The effects of two maximum grip strength training methods using the same effort duration and different edge depth on grip endurance in elite climbers. Sports Technol 2012;5(3-4):100-10. http://doi.org/10.1080/19346182.2012.716061.
10. Cutis A, Bollen SR. Grip strength and endurance in rock climbers. Proc Inst Mech Eng H 1993;207(2):87-92. http://doi.org/10.1243/PIME_PROC_1993_207_275_02. PMid:8280318.
11. Assmann M, Steinmetz G, Schilling AF, Saul D. Comparison of grip strength in recreational climbers and non-climbing athletes: a cross-sectional study. Int J Environ Res Public Health 2021;18(1):129. http://doi.org/10.3390/ijerph18010129. PMid:33375452.
12. Laffaye G, Levernier G, Collin J-M. Determinant factors in climbing ability: influence of strength, anthropometry, and neuromuscular fatigue. Scand J Med Sci Sports 2015;26(10):1151-9. PMid:26453999.
13. Baláš J, Pecha O, Martin AJ, Cochrane D. Hand–arm strength and endurance as predictors of climbing performance. Eur J Sport Sci 2012;12(1):16-25. http://doi.org/10.1080/17461391.2010.546431.
14. Draper N, Giles D, Taylor N, Vigouroux L, España-Romero V, Baláš J, et al. Performance assessment for rock climbers: the International Rock Climbing Research Association sport-specific test battery. Int J Sports Physiol Perform 2021;16(9):1242-52. http://doi.org/10.1123/ijspp.2020-0672. PMid:33652414.

15. Mermier CM, Janot JM, Parker DL, Swan JG. Physiological and anthropometric determinants of sport climbing performance. Br J Sports Med 2000;34(5):359-65. http://doi.org/10.1136/bjsm.34.5.359. PMid:11049146.

16. Fernandes AA, Marins JCB. Teste de força de preensão manual: análise metodológica e dados normativos em atletas. Fisioter Mov 2011;24(3):567-78. http://doi.org/10.1590/S0103-51502011000300021.

17. Grant S, Hynes V, Whittaker A, Aitchison T. Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. J Sports Sci 1996;14(4):301-9. http://doi.org/10.1080/02640419608727715. PMid:8887209.

18. Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age Ageing 2011;40(4):423-9. http://doi.org/10.1093/ageing/afr051. PMid:21624928.

19. López-Rivera E, González-Badillo JJ. Comparison of the effects of three hangboard strength and endurance training programs on grip endurance in sport climbers. J Hum Kinet 2019;66(1):183-95. http://doi.org/10.2478/hukin-2018-0057. PMid:30988852.

20. López-Rivera E, González-Badillo JJ, España-Romero V. Which is the most reliable edge depth to measure maximum hanging time in sport climbers? Gait Posture 2022;91:59-65. http://doi.org/10.1016/j.gaitpost.2021.09.200. PMid:34649172.

21. Schweizer A, Hudek R. Kinetics of crimp and slope grip in rock climbing. J Appl Biomech 2011;27(2):116-21. http://doi.org/10.1123/jab.27.2.116. PMid:21576719.

22. Stefan RR, Camic CL, Miles GF, Kovacs AJ, Jagim AR, Hill CM. Relative contributions of handgrip and individual finger strength on climbing performance in a bouldering competition. Int J Sports Physiol Perform 2022;17(5):768-73. http://doi.org/10.1123/ijspp.2021-0422. PMid:35235904.

23. Arazi H, Rashidlamir A, Abolhasani MZ, Hosaini SA. Profiling and predicting performance of indoor rock climbers. Rev Bras Cineantropom Desempenho Hum 2018;20(1):82-94. http://doi.org/10.5007/1980-0037.2018v20n1p82.

24. Watts PB. Physiology of difficult rock climbing. Eur J Appl Physiol 2004;91(4):361-72. http://doi.org/10.1007/s00421-003-1036-7. PMid:14985990.