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# Assessment of predictors of lead climbing performance in Kazakhstani rock climbers

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**Abstract**

*Background and Study Aim* Finger flexor strength and endurance are components of lead climbing performance. Climbers develop these qualities within specific training environments shaped by facility characteristics and coaching practices. Despite the application of various strength and endurance assessments in climbing training, their relative effectiveness in explaining performance within a unified training system remains a matter of practical interest. The aim of the study is to assess the relationship between finger strength and endurance measures and lead climbing performance in climbers trained within a unified sports school system.

*Material and Methods* A cross-sectional study was conducted with 38 competitive climbers (16 females, 22 males; mean age 21.8 ± 11.0 years) from one climbing school in Astana, Kazakhstan. Testing was performed during a training camp in Burabay. Participants completed five field-based finger flexor tests: maximal voluntary contraction, grip dynamometry, continuous endurance at 60% maximal voluntary contraction, intermittent endurance at 60% maximal voluntary contraction, and finger hang time on a 23 mm edge. Climbing performance was assessed using onsight and red point grades based on the IRCRA scale. Pearson correlation coefficients were calculated to examine associations between physiological variables and climbing performance. Analyses were conducted across gender and skill subgroups: Intermediate (n = 14), Advanced (n = 18), and Elite (n = 6).

*Results* Maximal voluntary contraction and finger hang time were moderately correlated with onsight ($r = 0.543$ and $r = 0.625$; $p < 0.01$) and red point performance ($r = 0.546$ and $r = 0.603$; $p < 0.01$). Continuous endurance showed no significant association with onsight ($r = -0.095$) or red point grades ($r = -0.041$). Among female climbers, intermittent endurance was associated with onsight performance ($r = 0.628$, $p < 0.05$). In the Advanced group, maximal voluntary contraction was associated with red point performance ($r = 0.665$, $p < 0.01$). In the Elite group, maximal voluntary contraction and grip dynamometry were strongly associated with onsight performance ($r = 0.866$ and $r = 0.860$; $p < 0.05$).

*Conclusions* The findings underline the importance of aligning finger strength and endurance assessment with the training context and the developmental stage of climbers. Test selection and training focus should reflect the specific demands imposed by the training environment rather than relying on uniform evaluation protocols. These considerations may support more targeted planning of training and monitoring strategies in lead climbing. Further longitudinal research involving multiple training centers is required to clarify how training context influences performance-related adaptations.

**Keywords:** finger flexor endurance, maximal voluntary contraction, hangboard testing, performance prediction, climbing-specific strength, training homogeneity

## Introduction

Lead climbing performance emerges from the interaction of physical capacities, technical execution, and training context. Among these factors, finger force production and fatigue resistance place specific demands on climbers due to the repetitive loading of small holds and sustained grip actions. The relative contribution of different strength and endurance qualities is shaped by training structure, facility characteristics, and athlete level, which together influence how physiological capacities are expressed in performance. As a result, evaluating performance-related indicators requires consideration of both the measured variables and the environment in which climbers are trained and assessed.

Rock climbing has evolved from a niche outdoor pursuit into a globally recognized competitive sport, reflected in its inclusion in the Olympic Games and the development of standardized performance metrics across disciplines such as lead climbing, bouldering, and speed climbing [1]. Lead climbing, characterized by technical complexity, sustained physical effort, and strategic route navigation, places substantial demands on the climber's neuromuscular


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system. These demands primarily involve the upper limbs and the finger flexors. The biomechanical and physiological basis of climbing performance has received growing scientific attention. This interest is linked to the identification of performance-related indicators relevant to training organization, athlete development, and injury prevention. Although technique, psychological factors, and tactical decision-making contribute to climbing performance, available evidence indicates that finger strength and endurance represent relevant physiological determinants in lead climbing [2].

Despite evidence linking finger flexor capacity to climbing performance, much existing research is based on heterogeneous cohorts of athletes trained under different coaching philosophies, geographic traditions, or periodization models. Such variability complicates the separation of physiological predictors from methodological or environmental confounders. Maximal isometric strength and hangboard endurance are frequently used as performance indicators, but their relative contribution may vary with climbing level and with the structure of the training system [3]. Few studies have examined climbers trained within a single, clearly defined framework in which technical instruction, periodization, and recovery protocols are standardized. This setting allows a clearer examination of strength- and endurance-related contributions with reduced influence of external training factors. In addition, the relationship between muscle recovery kinetics and performance, particularly during planned deload or competition phases, remains insufficiently characterized in non-elite and developing climbing populations [4]. These issues are relevant in regions such as Central Asia, where competitive climbing is expanding under specific training and infrastructure conditions.

The climbing characteristics of athletes from different climbing schools differ and are influenced by training approaches. Some authors suggest that variations in technical skill and tactical behavior depend on athletes' physical qualities and training level [5]. Finger strength has been examined as a determinant of climbing performance, but evidence derived from large samples trained within a single training system remains limited [6]. Muscle recovery during periods of reduced or absent loading has received less systematic attention. Available data suggest an association between finger strength and recovery capacity, although methodological constraints indicate that these observations require further verification [7].

Recent international studies have identified climbing-specific finger strength, particularly maximal isometric force production on standardized edges, as a physiological correlate of performance in bouldering and lead climbing. Buraas et al. showed that weighted hangs on a 22-mm edge explained up to 79% of the variance in bouldering performance and 46% in redpoint performance in a heterogeneous sample of male climbers (grades 6b+–8c). These values exceeded those reported for general measures such as handgrip strength or pull-up performance [8]. Similar associations between finger flexor capacity and climbing level were reported by Baláš et al. [9] and Giles et al. [10] across climbers with different training backgrounds and from different regions.

In contrast, Hermans et al. [11] reported that intermediate-to-advanced climbers engaged in self-directed training achieved improvements in finger strength and endurance following structured hangboard interventions. These results suggest that endurance-related traits may remain relevant at sub-elite levels, where technical efficiency and route-reading skills continue to develop. Most evidence of this type is derived from Western cohorts with access to varied wall angles, outdoor climbing areas, and periodized training infrastructure. Such conditions may influence the contribution of endurance and technical adaptability to climbing performance.

Pérez-Cordero et al. [12] reported that maximal isometric finger strength measured on fixed 20–23 mm edges shows high test–retest reliability (ICC > 0.85) across climbers ranging from recreational to elite levels, across age groups, and in both sexes. This supports its use as a performance marker with consistent measurement properties. In this context, the term "universal" refers to methodological robustness and cross-population consistency. When assessed under standardized conditions, such as half-crimp or open-hand grips on 20–23 mm edges, maximal isometric finger strength provides reproducible and environment-relevant data across different training systems and geographic settings.

Schweizer et al. [13] reported that the addition of dynamic eccentric–concentric finger flexor training to regular climbing practice was associated with improvements in redpoint, onsight, and bouldering performance in recreational and advanced climbers. The results indicate that strength-related adaptations may transfer across climbing disciplines when training is self-directed and varied.

Mundry et al. [14] reported that in a heterogeneous group of intermediate-to-advanced climbers (UIAA VI–VIII), hangboard training based on progressive external loading led to increases in maximal grip strength. The effects were most evident in multi-finger pinch configurations involving three or more digits. By contrast, training based on reducing edge depth to target finger endurance produced minimal changes in strength-related outcomes. These findings suggest that, at sub-elite levels, maximal force production may respond more readily to structured finger training than localized endurance, particularly in climbers without prior systematic finger-strength training experience.

González-Martín et al. [15] reported that climbing-specific isometric strength, assessed using half-crimp and three-finger drag positions, differentiates climbers from non-climbers, whereas generic handgrip dynamometry does not. The authors also showed that muscle quality, defined as force relative to forearm muscle mass, is associated with climbing strength, indicating the role of neuromuscular efficiency rather than muscle hypertrophy.

Levernier and Laffaye [16] reported that maximal isometric finger force and the rate of force development discriminate between non-climbers, skilled climbers (French grade 7c–8a), and international-level climbers (⩾8b). Absolute and body-mass-normalized maximal force was higher in skilled climbers than in non-climbers and further increased in international-level climbers. Measures of the rate of force development at 200 ms and at 95% of maximal force also differed across groups, with higher values observed at higher competitive levels. These results indicate that maximal finger strength is relevant across performance levels, whereas rapid force production becomes more pronounced with increasing climbing level, consistent with adaptations of neuromuscular control and musculoskeletal properties developed through long-term climbing practice.

Marcolin et al. [17] reported that in a mixed group of advanced and intermediate climbers, finger flexor strength and endurance assessed under high-fatigue conditions were more closely associated with climbing level than generic handgrip strength or low-fatigue endurance measures. Endurance measured after accumulated fatigue showed the strongest correlation with performance ($r = 0.74$). These results indicate that fatigue resistance, in addition to maximal strength, is relevant in heterogeneous and self-regulated training environments.

Ozimek et al. [18] reported that in elite male climbers (8b–8c redpoint), finger strength and arm endurance, assessed using pull-up repetitions and hang time on 2.5–4 cm ledges, differentiated them from advanced climbers (7c+–8a redpoint). Anthropometric measures, such as calf circumference, showed a lesser association with climbing level.

Analysis of previous research findings indicates that climbing performance is closely related to climbing-specific manifestations of finger strength, endurance, and force production dynamics across different performance levels. Researchers emphasize that the contribution of these physical qualities varies with athlete level, fatigue conditions, and the structure of the training environment, reflecting the multifactorial nature of lead climbing performance. At the same time, unresolved aspects remain regarding how these relationships are expressed within standardized training systems, where coaching methods, loading strategies, and environmental constraints are relatively uniform. This contextual specificity continues to limit the interpretation of performance-related indicators and complicates their application to targeted training and monitoring practices.

Taken together, previous findings indicate that finger strength and endurance are relevant to lead climbing performance and that their contribution may vary across training contexts and performance levels. In this context, it is assumed that testable hypotheses can be formulated regarding the role of finger strength and endurance within a standardized training system.

*Hypotheses:*

1. Finger strength and endurance measures are associated with lead climbing performance in climbers trained within a single sports school system.
2. The strength of these associations differs across competitive levels (intermediate, advanced, and elite).

*Purpose:* The aim of the study is to assess the relationships between finger strength and endurance indicators and lead climbing performance in climbers trained within one sports school.

## Materials and Methods

*Participants*

This study examined 38 participants during a training camp held in the Burabay region. The sample included 16 women and 22 men engaged in rock climbing in the city of Astana and training under the supervision of a single coach. For analytical purposes, participants were grouped by gender and climbing level. Climbing level was determined based on onsight and redpoint performance according to the IRCRA scale system [19].

Participants were eligible for inclusion if they were actively involved in competitive lead climbing within the national training system, trained under the supervision of a single head coach at the same climbing school in Astana, and had a minimum of two years of climbing experience. Exclusion criteria included any upper-limb injury or medical condition affecting finger flexor function within the previous three months, or the absence of written informed consent or parental consent for minors. All climbers training under the head coach were invited to participate during the scheduled training camp in the Burabay region. No financial incentives were provided. All recruited participants met the inclusion criteria and completed the testing protocol.

The study protocol received ethical approval from the Ethics Committee of the Academy of Physical Education and Mass Sports, Astana, Kazakhstan (reference number APEMS/EC-2025-014). All procedures were conducted in accordance with the

Declaration of Helsinki (2013 revision) and relevant national regulations governing research involving human participants. Written informed consent was obtained from a parent or legal guardian for all participants under 18 years of age, and assent was obtained from the minors themselves. Participation was voluntary, and all participants had the right to withdraw from the study at any stage without consequence.

*Study Design*

The study was designed as a subgroup-based analytical investigation to examine the relationships between finger flexor characteristics and the specific demands of lead climbing. This approach allowed comparisons across predefined performance groups rather than emphasizing sample size. Testing sessions were conducted during a period of peak performance to capture performance-relevant characteristics of the climbers.

*Testing Procedure and Measurements*

Testing was conducted from May 3 to May 11, 2025, in the Burabay rock area during a climbing festival in which the participants took part. During the testing period, participants' climbing performance was documented according to the climbing levels they demonstrated.

Five tests were performed in a mobile laboratory: (1) maximal voluntary contraction for both hands; (2) a continuous endurance test at 60% of maximal voluntary contraction using the weaker hand; (3) an intermittent endurance test at 60% of maximal voluntary contraction using the stronger hand; (4) a finger hang test; and (5) grip strength assessed by hand dynamometry [20, 21]. Rest intervals between tests were adjusted according to the metabolic demand and duration of each test. The duration and type of rest are specified in Figure 1.

Testing was performed using a Climbro hangboard (Climbro Ltd., Sofia, Bulgaria) mounted on a vertical frame. The hangboard was equipped with force sensors (sampling rate 100 Hz) and connected to a mobile application providing standardized instructions and real-time feedback on force and contraction time [22]. Finger flexor tests were conducted while facing the hangboard, using a 23 mm rounded edge with the dominant hand in an open-finger grip position [23]. Before testing, participants completed a standardized warm-up consisting of 5 minutes of aerobic activity, 10 minutes of mobilization exercises, and easy climbing. A fixed rest period was provided between tests (Figure 1).

All participants completed a standardized warm-up protocol prior to testing under the supervision of the research team to ensure consistency across subjects. The warm-up consisted of three sequential phases:

- 5 minutes of general aerobic activity (e.g., light jogging or dynamic movements);
- 10 minutes of climbing-specific mobilization drills focusing on shoulder, wrist, and finger mobility;
- 5–10 minutes of easy, self-paced climbing on low-intensity routes to activate the climbing-specific neuromuscular system.

The entire warm-up was conducted under the direct supervision of trained personnel, who verified adherence to timing, exercise selection, and intensity. No participant began testing without completing all warm-up components. This protocol aligns with recommendations of the International

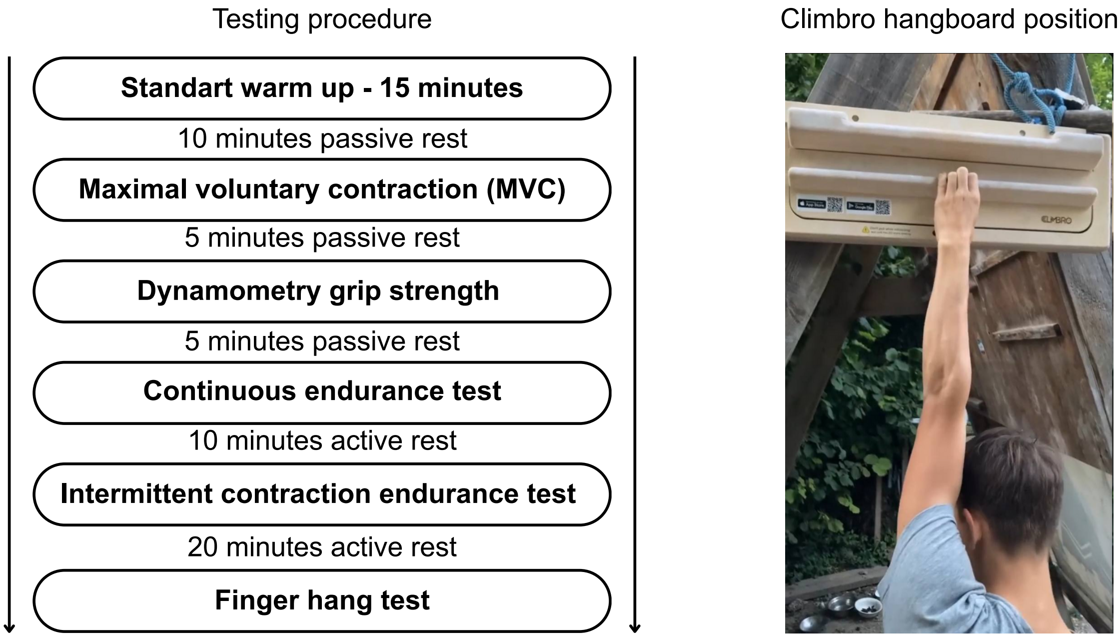


**Figure 1.** Finger flexor testing procedure and participant testing position.

Rock Climbing Research Association (IRCRA) for sport-specific performance testing [4, 12].

All testing procedures were conducted outdoors at the Burabay National Park climbing area during the annual rock climbing festival. Environmental conditions were monitored daily. Ambient temperature ranged from 14°C to 22°C, relative humidity from 45% to 65%, and testing was performed under cloudy to partly sunny conditions without precipitation. Wind speed remained below 10 km/h. All tests were conducted in shaded areas to reduce thermal and solar effects.

All physiological assessments were administered by a single lead investigator with experience in climbing-specific performance testing and formal training in standardized protocols recommended by the International Rock Climbing Research Association (IRCRA). This ensured consistency in test execution, verbal instructions, and monitoring of technique across participants. Two junior research assistants from the Kazakh National University of Sports supported the testing by managing logistics, collecting consent documentation, and completing paper-based data forms. The assistants received structured orientation on ethical procedures and data recording before testing. Data were recorded on standardized paper score sheets in the field and subsequently digitized in a secure office environment.

*Statistical Analysis*

The best lead climbing performance achieved by each athlete was used as the dependent variable and correlated with indicators of finger strength and endurance. Pearson correlation coefficients were calculated to examine associations between variables. Statistical analyses were performed using IBM SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test and visual inspection of Q–Q plots and histograms. All variables, including maximal voluntary contraction, finger hang time, continuous and intermittent endurance, dynamometry, and climbing grades, showed acceptable normality ($p > 0.05$), supporting the use of parametric correlation analysis.

No missing data were present, as all participants completed the full testing protocol. Potential outliers were assessed using boxplots and standardized z-scores ($|z| > 3.29$). Two values in the intermittent endurance test exceeded this threshold; however, both reflected plausible performance variability in elite climbers and were retained. Additional analyses excluding these cases yielded similar correlation patterns and significance levels.

## Results

Descriptive characteristics of the participants and outcomes of the finger strength and endurance tests are presented in Tables 1 and 2. No systematic differences were observed between left and right hands for maximal voluntary contraction, therefore averaged values were used in subsequent analyses.

Correlation analysis showed that finger flexor strength and hang-related performance were associated with lead climbing level. Maximal voluntary contraction and finger hang time demonstrated consistent positive relationships with both onsight and redpoint performance across the full sample. In contrast, continuous endurance showed no meaningful association with climbing performance, while grip dynamometry displayed weak and non-significant relationships.

Sex-specific analyses revealed different association patterns. In female climbers, intermittent endurance was related to onsight performance, whereas maximal strength measures showed weaker and inconsistent relationships. In male climbers, maximal voluntary contraction and finger hang performance were more closely associated with onsight climbing level, while associations with redpoint performance were less consistent.

When climbers were grouped by performance level, distinct patterns emerged. In intermediate climbers, finger hang performance showed the strongest relationship with climbing level. In the advanced group, maximal voluntary contraction was most strongly associated with redpoint performance, alongside moderate associations with grip strength. In elite climbers, both maximal voluntary contraction and grip dynamometry demonstrated strong relationships with onsight performance, whereas endurance-based measures showed weaker or inconsistent associations.

Overall, the results indicate that the relative contribution of finger strength and endurance measures to lead climbing performance differs across sex and performance level, with strength-related variables showing stronger associations at higher climbing levels and endurance-related measures playing a more variable role.

*Results by Gender*

When analyzed by gender, distinct association patterns were observed (Table 2). Among females ($n = 16$), finger hang endurance was associated with onsight performance, and intermittent endurance showed a moderate positive relationship. Maximal voluntary contraction demonstrated a moderate association with onsight performance, although it did not reach the stricter significance threshold. Grip dynamometry showed a negative and non-significant trend, indicating limited relevance in this subgroup.

In males ($n = 22$), maximal voluntary contraction was strongly associated with onsight performance, and finger hang time showed the highest association among the examined variables (Table 2). In contrast, no consistent associations were observed between physical variables and redpoint performance. Only

**Table 1.** Results of testing the participants of the experiment

| Group, n | Weight, kg | Age, years | MVC, kg | | | Dynamometry, kg | | | Continuous test, sec | Intermittent test, sec | Finger hang, sec | Climbing level | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Left | Right | Average | Left | Right | Average | | | | OS | RP |
| All, 38 | 55.9±11.2 | 21,8±11 | 45.2±13.2 | 46±13.4 | 46±13.4 | 32.8±12.6 | 35.7±13.1 | 34.2±12.7 | 40.9±17 | 215±99 | 39.6±21 | 14.7±3.5 | 18.4±3.9 |
| **Gender** | | | | | | | | | | | | | |
| Female, 16 | 49.6±7.8 | 22.3±13.3 | 35.9±6.5 | 36.5±6.5 | 36.2±6.4 | 22.9±4.6 | 24.6±5.4 | 23.7±4.9 | 42.2±16.0 | 236±102 | 32.9±19 | 14.1±2.6 | 17.1±3.2 |
| Male, 22 | 60.8±10.9 | 21.8±10 | 52±12.9 | 52.8±13.2 | 52.4±12.9 | 40±11.7 | 43.5±11.5 | 41.7±11.4 | 38.8±17.4 | 201±100 | 43.2±21.8 | 15.2±4 | 19.2±4.2 |
| **Climbing level** | | | | | | | | | | | | | |
| Intermediate, 14 | 55.5±12.1 | 21.9±12.4 | 42.1±13.2 | 43.2±14.1 | 42.6±13.6 | 34.5±13.1 | 37.9±13 | 36.2±12.8 | 41.2±14.1 | 190±85.2 | 29.8±17.6 | 11.8±1.7 | 14.7±1.7 |
| Advanced, 18 | 54.6±10.4 | 23.3±12.4 | 44.4±12.4 | 44.9±12.1 | 44.6±12.2 | 29.4±12.3 | 32.2±13.1 | 30.8±12.6 | 40.3±12.7 | 241±119 | 41±19.1 | 15.6±2.4 | 19.4±2.9 |
| Elite, 6 | 62.7±11.5 | 18.5±5.4 | 56.3±15.2 | 56.7±16 | 56.5±15.6 | 40.2±13.7 | 41±16 | 40.6±14.8 | 37.5±21.8 | 200±66 | 55.2±23.3 | 19.2±2.8 | 24±1.8 |

Note. Data are presented as mean ± standard deviation. MVC – maximal voluntary contraction. Dynamometry values represent handgrip strength. Continuous and intermittent tests were performed at 60% of MVC. Finger hang time was measured on a 23 mm edge. OS – onsight grade; RP – redpoint grade. Climbing grades are reported according to the IRCRA scale.

**Table 2.** Correlation relationship between the results of the experiment and the level of climbing

| Group, n | Climbing type | Weight | Age | MVC | | | Dynamometry | | | Continuous test | Intermittent test | Finger hang |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Left | Right | Average | Left | Right | Average | | | |
| All, 38 | OS | 0.249 | 0.05 | 0.55** | 0.529** | 0.543** | 0.246 | 0.215 | 0.233 | -0.95 | 0.273 | 0.625** |
| | RP | 0.269 | -0.008 | 0.549** | 0.537** | 0.546** | 0.276 | 0.241 | 0.261 | -0.041 | 0.150 | 0.603** |
| **Gender** | | | | | | | | | | | | |
| Female, 16 | OS | 0.176 | 0.109 | 0.452 | 0.506 | 0.484 | -0.135 | -0.335 | -0.253 | -0.095 | 0.628* | 0.521* |
| | RP | 0.107 | 0.087 | 0.334 | 0.342 | 0.342 | -0.192 | -0.417 | -0.326 | 0.028 | 0.355 | 0.468 |
| Male, 22 | OS | 0.198 | 0.022 | 0.602** | 0.557** | 0.584** | 0.240 | 0.238 | 0.244 | -0.067 | 0.178 | 0.672** |
| | RP | 0.377 | 0.924 | 0.003 | 0.007 | 0.004 | 0.281 | 0.286 | 0.274 | 0.767 | 0.428 | 0.001 |
| **Climbing level** | | | | | | | | | | | | |
| Intermediate, 14 | OS | 0.127 | -0.405 | 0.430 | 0.398 | 0.416 | 0.220 | 0.230 | 0.229 | 0.180 | 0.104 | 0.596* |
| | RP | 0.022 | -0.485 | 0.421 | 0.383 | 0.404 | 0.234 | 0.153 | 0.197 | 0.287 | 0.227 | 0.665** |
| Advanced, 18 | OS | 0.152 | 0.406 | 0.424 | 0.438 | 0.434 | 0.196 | 0.193 | 0.196 | -0.051 | 0.410 | 0.460 |
| | RP | 0.370 | 0.403 | 0.630** | 0.691** | 0.665** | 0.511* | 0.576* | 0.548* | -0.032 | 0.090 | 0.439 |
| Elite, 6 | OS | 0.453 | 0.543 | 0.859* | 0.871* | 0.866* | 0.837* | 0.878* | 0.860* | 0.311 | 0.184 | 0.719 |
| | RP | 0.488 | 0.334 | 0.737 | 0.803 | 0.772 | 0.718 | 0.753 | 0.738 | -0.221 | 0.076 | 0.618 |

Note. Values represent Pearson correlation coefficients (r). MVC – maximal voluntary contraction; dynamometry – handgrip strength; OS – onsight grade; RP – redpoint grade, reported according to the IRCRA scale. For strength variables, average values of left and right hands were used. Correlations were calculated separately within each subgroup. ** $p < 0.01$, * $p < 0.05$.

body weight and age showed notable correlations, which should be interpreted with caution given subgroup size and variability.

*Results by Climbing Level*

Analysis across performance subgroups including Intermediate (n = 14), Advanced (n = 18), and Elite (n = 6) revealed differences in the pattern of associations between physical variables and climbing performance (Table 2).

In the Intermediate group, finger hang endurance showed the strongest associations with both onsight and redpoint performance. Maximal voluntary contraction demonstrated moderate relationships with climbing level, but these associations were weaker than those observed for endurance-related measures, indicating a greater relevance of endurance at lower performance levels.

Among Advanced climbers, maximal voluntary contraction and grip dynamometry were more closely associated with redpoint performance (Table 2). Strength-related measures showed stronger relationships than endurance-based indicators, suggesting a shift toward maximal force production as performance level increases. Finger hang endurance displayed weaker associations in this subgroup.

In the Elite subgroup, the strongest relationships were observed between strength-related variables and onsight performance (Table 2). Maximal voluntary contraction and dynamometry showed consistently high associations, whereas endurance-based measures demonstrated fewer stable relationships, likely influenced by the small sample size.

*Mutual Influence*

To examine interrelationships among indicators of finger flexor strength, Pearson correlation analysis was performed (Table 3). Strong and statistically significant positive correlations were observed among maximal voluntary contraction values for the left hand, right hand, and averaged scores. Grip dynamometry showed high consistency between hands and was strongly associated with maximal voluntary contraction, indicating convergence between these measures of maximal finger strength.

Interrelationships among finger flexor strength and endurance indicators are presented in Table 3. Measures of maximal voluntary contraction and grip dynamometry showed strong positive associations, reflecting internal consistency among maximal strength indicators. In contrast, endurance-based tests demonstrated weak to moderate inverse relationships with maximal strength measures. Intermittent endurance displayed statistically significant negative associations with strength-related variables, whereas continuous endurance showed weaker and largely non-significant relationships. Finger hang performance was positively associated with maximal voluntary contraction, while its relationships with other endurance measures were less pronounced.

## Discussion

The purpose of this study was to assess the relationships between finger strength and endurance indicators and lead climbing performance in climbers trained within a single sports school system. The results indicate that finger flexor strength and hang-related performance are associated with climbing level, whereas continuous endurance shows limited relevance. In addition, the pattern of associations differs across gender and performance subgroups, suggesting that the contribution of strength- and endurance-related measures varies with climbing level within a standardized training context.

Overall, the findings support the view that performance determinants in sport climbing are

**Table 3.** Correlation analysis of finger flexor muscle test scores

| Variable | | MVC | | | Dynamometry | | | Cont. test | Inter. test | Finger hang |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Left | Right | Average | Left | Right | Average | | | |
| MVC | Left | 1 | | | | | | | | |
| | Right | 0.978** | 1 | | | | | | | |
| | Average | 0.994** | 0.995** | 1 | | | | | | |
| Dynamometry | Left | 0.845** | 0.843** | 0.849** | 1 | | | | | |
| | Right | 0.855** | 0.855** | 0.860** | 0.956** | 1 | | | | |
| | Average | 0.860** | 0.858** | 0.864** | 0.988** | 0.989** | 1 | | | |
| Continuous test | | -0.212 | -0.265 | -0.240 | -0.236 | -0.231 | -0.236 | 1 | | |
| Intermittent test | | -0.337* | -0.337* | -0.339* | -0.440** | -0.442** | -0.446** | 0.443** | 1 | |
| Finger hang | | 0.477** | 0.463** | 0.473** | 0.227 | 0.245 | 0.239 | 0.270 | 0.289 | 1 |

Note. Cont. test= Continuous test; Inter. test= Intermittent test; Values represent Pearson correlation coefficients (r). MVC – maximal voluntary contraction. Dynamometry refers to handgrip strength. Left, right, and average indicate measurements obtained from the respective hands or their mean values. ** $p < 0.01$, * $p < 0.05$.

influenced by the organization of training rather than representing universal predictors. In this homogeneous cohort of Kazakhstani climbers trained under a single coach, maximal voluntary contraction and finger hang endurance showed consistent associations with both onsight and redpoint performance. These observations are in line with recent syntheses of climbing performance determinants, which emphasize the context-dependent role of finger strength and endurance across different climbing populations [6].

The findings should be interpreted in relation to the training environment in which the athletes were prepared. In Kazakhstan, long winters and limited access to natural rock substantially restrict opportunities for outdoor climbing, resulting in a predominant reliance on indoor facilities. Climbing gyms in urban centers such as Astana are typically characterized by low wall heights and pronounced overhangs, which favor strength- and power-oriented movement patterns over sustained climbing on vertical terrain. Such facility characteristics are known to shape both training content and performance demands in competitive climbing [1, 4, 19]. Consequently, the performance-related characteristics observed in this cohort reflect the combined influence of the applied training approach and the existing infrastructural conditions.

The analysis of gender-specific predictors revealed both shared and distinct patterns between male and female climbers within this homogeneous cohort. Finger hang endurance was associated with onsight performance in both groups, with a stronger association observed in males. Intermittent endurance was associated with onsight performance only in female climbers, indicating a potential role of repeated submaximal contractions and fatigue resistance within this training context. This pattern is consistent with previous findings reporting a greater contribution of endurance-related qualities in female climbers, particularly when climbing-specific strength is lower [20, 21, 15].

In contrast, no physiological variable showed a stable association with redpoint performance in males. The strong association observed between age and redpoint level in this subgroup should be interpreted with caution, as it may be influenced by the small sample size and limited age variability. Similar constraints have been reported in studies examining sex-related differences in climbing performance, where subgroup size and training background affect the stability of observed relationships [18]. Overall, these findings suggest that gender-specific patterns observed in this study are shaped by training context and methodological factors rather than reflecting fixed physiological differences.

A consistent pattern observed in this study is a shift in performance-related associations across climbing levels, with endurance-related variables showing greater relevance at lower levels and strength-related variables becoming more prominent as performance level increases. In the Intermediate group, finger hang endurance showed the strongest associations with onsight and redpoint performance, whereas maximal voluntary contraction demonstrated weaker relationships. This pattern is consistent with reports indicating that endurance-related capacities contribute more strongly to performance in less advanced climbers [9, 17].

In the Advanced group, maximal voluntary contraction showed a stronger association with redpoint performance, and grip dynamometry also became relevant. Similar transitions toward greater reliance on maximal strength with increasing climbing level have been reported in previous studies [8, 11, 14]. In the Elite subgroup, strength-related measures showed the strongest associations with onsight performance, while endurance-related indicators were less prominent. Although these findings should be interpreted cautiously due to the small size of the elite subgroup, they are in line with evidence indicating that maximal force production and rapid force expression become increasingly relevant at higher performance levels [16].

The present study indicates a distinct pattern of physiological predictors of lead climbing performance within a homogeneous cohort trained under a single coach and a standardized methodology in Kazakhstan. In contrast to findings from heterogeneous samples, in which maximal finger strength and endurance often jointly relate to performance [11, 17], the present results point to a more limited set of relevant predictors. Within this training system, maximal voluntary contraction and finger hang performance showed consistent associations with both onsight and redpoint climbing level, whereas continuous endurance did not demonstrate a meaningful relationship with performance.

These differences appear to be closely related to the characteristics of the training environment. Climbers in Kazakhstan train predominantly indoors on low walls with pronounced overhangs, which provide limited exposure to vertical or slab routes requiring prolonged isometric endurance. Such conditions favor adaptations related to maximal force production rather than sustained fatigue resistance. A similar context-dependent reduction in the relevance of generic strength measures has been reported in studies comparing system-specific and mixed training environments [8, 17].

Previous research has also identified rate of force development and muscle quality as important discriminators of elite performance, particularly in bouldering or more dynamic climbing disciplines [15, 16]. These variables were not assessed in the present field-based protocol. Their absence further emphasizes that the set of relevant performance determinants depends on both the climbing discipline and the training context. Taken together, these observations support the view that physiological predictors of climbing performance are not universal but are shaped by the structure of the training system and the environmental constraints under which athletes develop [7].

Thus, the homogeneity of coaching, periodization, and facility design in this cohort appears to narrow the range of physiological factors associated with lead climbing performance. Within this training context, strength-related measures show greater relevance, whereas endurance-related indicators play a more limited role. These findings support a context-dependent interpretation of climbing performance predictors rather than a universal framework.

*Limitations*

Despite the controlled training background and contextual relevance of this study, several limitations should be acknowledged. The relatively small sample size, particularly in subgroup analyses, limits statistical power and may affect the stability of observed associations. The inclusion of climbers trained under a single coach enhances internal consistency but restricts the generalizability of the findings to other training systems or climbing contexts. In addition, the cross-sectional design does not allow causal inference regarding the role of finger strength and endurance in performance development. Finally, the absence of associations for the continuous endurance test may be influenced by the specific testing protocol and task characteristics, which may not fully reflect the intermittent and dynamic fatigue patterns of lead climbing. These factors should be considered when interpreting the results.

*Proposed conceptual framework of finger strength development in lead climbing*

Based on the findings of the present study, a conceptual framework is proposed to summarize the progression of performance-related physiological determinants in lead climbing within infrastructure-constrained training systems (Figure 2). The framework describes a tiered progression in which the relative contribution of endurance- and strength-related indicators changes with climbing level. This progression is shaped by the interaction between training organization, facility characteristics, and environmental constraints. Within such systems, performance predictors are not fixed but vary systematically across developmental stages.

*Tier 1: Foundational Endurance (Intermediate Climbers, IRCRA 11–15)*

At the intermediate level, finger hang endurance on standardized edges represents the primary performance-related indicator. At this stage, climbers rely on the ability to sustain repeated submaximal contractions during route completion. Training environments characterized by low wall heights and steep angles limit opportunities for technical development on vertical terrain, resulting in repeated short efforts. Under these conditions, endurance-related capacity becomes a primary constraint on performance. *Testable hypothesis:* In intermediate climbers trained within homogeneous systems, finger hang endurance shows stronger associations with redpoint performance than maximal voluntary contraction.

*Tier 2: Strength Consolidation (Advanced Climbers, IRCRA 16–20)*

As climbers progress to advanced levels, maximal voluntary contraction and grip strength become more relevant to performance. Physiological adaptations at this stage are characterized by increased neural drive and tendon stiffness, while additional gains in endurance show diminishing returns. Training emphasis shifts toward higher

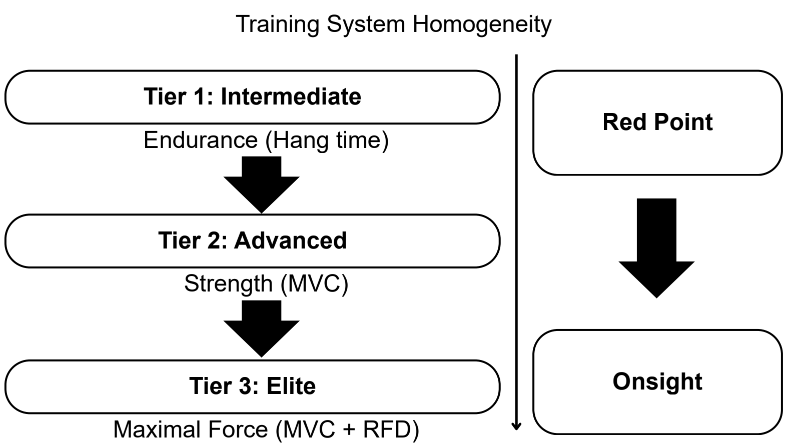


**Figure 2.** Context-modulated progression of performance determinants across climbing levels in Kazakhstani lead climbing systems.

isometric loading on smaller holds, reducing the relevance of continuous endurance tests conducted at fixed submaximal intensities. *Testable hypothesis:* In advanced climbers, maximal voluntary contraction demonstrates stronger associations with redpoint performance than endurance-based measures.

*Tier 3: Maximal Force Dominance (Elite Climbers, IRCRA 21+)*

At elite levels, performance is primarily constrained by maximal force production and relative finger strength. Endurance-related adaptations provide limited additional benefit, and performance is increasingly determined by the ability to generate high forces on small holds under conditions of fatigue and psychological pressure. In infrastructure-limited systems with minimal exposure to slab or vertical climbing, this transition toward strength dominance may occur earlier than reported in heterogeneous training contexts. *Testable hypothesis:* In elite climbers from infrastructure-constrained systems, maximal voluntary contraction and grip strength are associated with onsight performance, whereas fatigue-resistance indicators provide limited additional predictive value.

## Conclusions

Finger flexor strength and hang-related performance indicators are associated with lead climbing performance in climbers trained within a single, homogeneous coaching system. Among the assessed variables, finger hang endurance and maximal voluntary contraction showed the most consistent relationships with onsight and redpoint performance, whereas continuous endurance demonstrated limited relevance under the examined training conditions.

The findings indicate a shift in performance-related determinants across climbing levels. Endurance-related indicators are more relevant at intermediate stages, while maximal strength becomes increasingly important at advanced and elite levels. In addition, gender-specific patterns were observed, with intermittent endurance showing an association with onsight performance only in female climbers. These observations suggest that the relevance of physiological characteristics varies with performance level and training context.

Overall, the results highlight the influence of training environment and infrastructure on the manifestation of performance predictors. In settings characterized by limited outdoor access and predominantly overhanging indoor facilities, strength-related measures appear to play a greater role in performance assessment. The findings may inform practical monitoring and training decisions in similar training systems, while emphasizing the need for cautious interpretation due to sample size constraints.

## References

1. Lutter C, Tischer T, Schöffl VR. Olympic competition climbing: the beginning of a new era—a narrative review. *British Journal of Sports Medicine*, 2021;55(15): 857–864. https://doi.org/10.1136/bjsports-2020-102035
2. Winkler M, Künzell S, Augste C. Competitive performance predictors in speed climbing, bouldering, and lead climbing. *Journal of Sports Sciences*, 2023;41(8): 736–746. https://doi.org/10.1080/02640414.2023.2239598
3. Giles LV, Rhodes EC, Taunton JE. The Physiology of Rock Climbing: *Sports Medicine*, 2006;36(6): 529–545. https://doi.org/10.2165/00007256-200636060-00006
4. 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. *International Journal of Sports Physiology and Performance*, 2021;16(9): 1242–1252. https://doi.org/10.1123/ijspp.2020-0672
5. Sibella F, Frosio I, Schena F, Borghese NA. 3D analysis of the body center of mass in rock climbing. *Human Movement Science*, 2007;26(6): 841–852. https://doi.org/10.1016/j.humov.2007.05.008
6. Faggian S, Borasio N, Vecchiato M, Gatterer H, Burtscher M, Battista F, et al. Sport climbing performance determinants and functional testing methods: A systematic review. *Journal of Sport and Health Science*, 2025;14: 100974. https://doi.org/10.1016/j.jshs.2024.100974
7. Son S, Seo Y, Son J, Yun S, Lee DT. Comparison of finger flexion strength and muscular recovery of male lead sport climbers across climbing classes. *Physical Therapy in Sport*, 2024;65: 122–129. https://doi.org/10.1016/j.ptsp.2023.12.007
8. Buraas BF, Brobakken MF, Wang E. Climbing performance in males: the importance of climbing-specific finger strength. *European Journal of Applied Physiology*, 2025;125(10): 2823–2830. https://doi.org/10.1007/s00421-025-05802-5
9. Baláš J, Pecha O, Martin AJ, Cochrane D. Hand–arm strength and endurance as predictors of climbing performance. *European Journal of Sport Science*, 2012;12(1): 16–25. https://doi.org/10.1080/17461391.2010.546431
10. Giles D, Hartley C, Maslen H, Hadley J, Taylor N, Torr O, et al. An All-Out Test to Determine Finger Flexor Critical Force in Rock Climbers. *International Journal of Sports Physiology and Performance*, 2021;16(7): 942–949. https://doi.org/10.1123/ijspp.2020-0637
11. Hermans E, Saeterbakken AH, Vereide V, Nord ISO, Stien N, Andersen V. The Effects of 10 Weeks Hangboard Training on Climbing Specific Maximal Strength, Explosive Strength, and Finger Endurance. *Frontiers in Sports and Active Living*, 2022;4: 888158. https://doi.org/10.3389/fspor.2022.888158

12. Pérez-Cordero J, Jerez-Mayorga D, Rodríguez-Perea Á, Soto García D. Reliability of finger strength assessment methods in climbing: a systematic review. *Frontiers in Sports and Active Living*, 2025;7: 1650198. https://doi.org/10.3389/fspor.2025.1650198
13. Schweizer A, Schneider A, Goehner K. Dynamic eccentric-concentric strength training of the finger flexors to improve rock climbing performance. *Isokinetics and Exercise Science*, 2007;15(2): 131–136. https://doi.org/10.3233/IES-2007-0259
14. Mundry S, Steinmetz G, Atkinson EJ, Schilling AF, Schöffl VR, Saul D. Hangboard training in advanced climbers: A randomized controlled trial. *Scientific Reports*, 2021;11(1): 13530. https://doi.org/10.1038/s41598-021-92898-2
15. González-Martín D, Santos-Pérez J, Maroto-Izquierdo S, De Paz JA, Gallego-Selles Á. Comparison of Finger Flexor Strength and Muscle Quality Between Climbers and Non-Climbers: Influence of Sex and Grip Type. *Applied Sciences*, 2025;15(13): 7161. https://doi.org/10.3390/app15137161
16. Levernier G, Laffaye G. Rate of force development and maximal force: reliability and difference between non-climbers, skilled and international climbers. *Sports Biomechanics*, 2021;20(4): 495–506. https://doi.org/10.1080/14763141.2019.1584236
17. Marcolin G, Faggian S, Muschietti M, Matteraglia L, Paoli A. Determinants of Climbing Performance: When Finger Flexor Strength and Endurance Count. *Journal of Strength & Conditioning Research*, 2022;36(4): 1099–1104. https://doi.org/10.1519/JSC.0000000000003545
18. 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. Earnest CP (ed.) *PLOS ONE*, 2017;12(8): e0182026. https://doi.org/10.1371/journal.pone.0182026
19. Draper N, Giles D, Schöffl V, Konstantin Fuss F, Watts P, Wolf P, et al. Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. *Sports Technology*, 2015;8(3–4): 88–94. https://doi.org/10.1080/19346182.2015.1107081
20. Assmann M, Steinmetz G, Schilling AF, Saul D. Comparison of Grip Strength in Recreational Climbers and Non-Climbing Athletes—A Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, 2020;18(1): 129. https://doi.org/10.3390/ijerph18010129
21. Berta P, Michailov M, Kaško D, Gajdošík J, Běhounek M, Baláš J. Validity and normative scores of finger flexor strength and endurance tests estimated from a large sample of female and male climbers. *Journal of Sports Sciences*, 2025;43(3): 245–255. https://doi.org/10.1080/02640414.2024.2449316
22. Michailov M, Baláš J. Reliability and validity of various force-time indicators for the assessment of finger and shoulder girdle strength in climbing. *Journal of Applied Sports Sciences*, 2023;7(1): 3–14. https://doi.org/10.37393/JASS.2023.01.1
23. Torr O, Randall T, Knowles R, Giles D, Atkins S. Reliability and Validity of a Method for the Assessment of Sport Rock Climbers' Isometric Finger Strength. *Journal of Strength & Conditioning Research*, 2022;36(8): 2277–2282. https://doi.org/10.1519/JSC.0000000000003548

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