



Quantifying climbing potential: a multivariate model of finger flexor readiness for performance progression

Cuantificación del potencial de escalada: un modelo multivariado de la preparación de los flexores de los dedos para la progresión del rendimiento

Authors

Shunko Andrey
Mukhambet Zhassyn
Sydykov Nurbol
Kenzhin Zhaxat
Beibit Duman

¹ Kazakh National University of Sport (Kazakhstan)

Corresponding author:
Shunko Andrey
shunko.a@yahoo.com

Received: 01-04-26
Accepted: 20-05-26

How to cite in APA

Shunko, A., Mukhambet, Z., Sydykov, N., Kenzhin, Z., & Beibit, D. (2026). Quantifying climbing potential: a multivariate model of finger flexor readiness for performance progression. *Retos*, 81, 365-379.
<https://doi.org/10.47197/retos.v81.119156>

Abstract

Introduction: researchers identified finger flexor strength and endurance as critical determinants of sport climbing performance, yet predictive models for longitudinal progression remained underdeveloped.

Objective: the study aimed to construct a multivariate readiness model to guide training periodization for lead climbing advancement.

Methodology: sixty four competitive climbers from a single coaching system completed standardized assessments of maximal voluntary contraction, continuous and intermittent endurance at sixty percent maximal contraction, finger hang duration, and dynamometry, and the researchers applied pearson correlations to analyze physiological predictors against climbing grades.

Results: finger hang duration emerged as the strongest predictor of red point performance, exceeded maximal contraction values, demonstrated that continuous endurance held no significant association with climbing grades, and revealed that predictor importance shifted toward maximal strength at higher performance levels.

Discussion: these outcomes corroborated existing literature that established finger capacity as the primary physiological determinant, and confirmed that sport specific endurance protocols possessed superior ecological validity compared to generalized strength metrics.

Conclusion: the proposed tiered framework successfully identified discipline specific readiness thresholds and should be integrated into coaching practice to optimize training periodization, though longitudinal validation remains necessary to confirm predictive accuracy.

Keywords

Finger flexor endurance, maximal voluntary contraction, hangboard testing, performance prediction, climbing-specific strength, training homogeneity.

Resumen

Introducción: Los investigadores identificaron la fuerza y la resistencia de los flexores de los dedos como determinantes críticos del rendimiento en la escalada deportiva; sin embargo, los modelos predictivos para la progresión longitudinal aún no estaban desarrollados.

Objetivo: El estudio tuvo como objetivo construir un modelo de preparación multivariante para guiar la periodización del entrenamiento en la escalada de dificultad.

Metodología: Sesenta y cuatro escaladores de competición de un mismo sistema de entrenamiento completaron evaluaciones estandarizadas de contracción voluntaria máxima, resistencia continua e intermitente al 60 % de la contracción máxima, duración de la suspensión de los dedos y dinamometría. Los investigadores aplicaron correlaciones de Pearson para analizar los predictores fisiológicos en relación con los grados de escalada.

Resultados: La duración de la suspensión de los dedos se reveló como el predictor más fuerte del rendimiento en escaladas de dificultad, superando los valores de contracción máxima. Se demostró que la resistencia continua no tenía una asociación significativa con los grados de escalada y se reveló que la importancia del predictor se desplazaba hacia la fuerza máxima en niveles de rendimiento más altos.

Discusión: Estos resultados corroboraron la literatura existente que establece la capacidad de los dedos como el principal determinante fisiológico y confirmaron que los protocolos de resistencia específicos para el deporte poseen una validez ecológica superior en comparación con las métricas de fuerza generalizadas. **Conclusión:** el marco escalonado propuesto identificó con éxito los umbrales de preparación específicos de cada disciplina y debería integrarse en la práctica del entrenamiento para optimizar la periodización del mismo, aunque sigue siendo necesaria una validación longitudinal para confirmar la precisión predictiva.

Palabras clave

Resistencia de los flexores de los dedos, contracción voluntaria máxima, prueba de entrenamiento en tabla de escalada, predicción del rendimiento, fuerza específica para la escalada, homogeneidad del entrenamiento.

Introduction

Sport climbing has evolved rapidly over the past decade into a highly competitive Olympic discipline, where marginal gains in physical performance often determine success at the elite level. Among the various physiological attributes required for climbing, the strength and endurance of the finger flexor muscles are widely recognized as the most critical factors distinguishing performance levels across all grades (Saul et al., 2019; Mermier et al., 2000). Recent evidence suggests that maximal voluntary contraction (MVC) and specific endurance capacities of the finger flexors correlate strongly with climbing grades, serving as key predictors of an athlete's current capability (Berta et al., 2025; Buraas et al., 2025). This relationship is particularly pronounced in lead climbing, where athletes must sustain sub-maximal forces over extended periods while managing accumulating fatigue. Consequently, accurate assessment of these parameters is essential not only for talent identification but also for precise training prescription and longitudinal performance monitoring.

Finger flexor strength is typically developed through specific resistance training, such as hangboard protocols. These protocols induce significant adaptations in force production and endurance (Stien et al., 2022; Devise et al., 2022). Research indicates that continuous and intermittent contraction protocols contribute uniquely to climbing performance. Continuous endurance reflects the ability to maintain grip force during sustained sections. In contrast, intermittent endurance mirrors the stop-and-go nature of modern lead climbing routes, where shaking out during rest positions is required (Stien et al., 2019). Training intensity also plays a pivotal role. Deviations from optimal loading zones can lead to diminishing returns or increased injury risk (Sjöman et al., 2023; Stien et al., 2023). While the relationship between strength metrics and current performance is well-documented, research on athlete readiness for progression remains limited. Most existing models focus on cross-sectional performance prediction rather than longitudinal progression potential (Faggian et al., 2024).

A systematic examination of recent literature reveals that approximately 80% of empirical studies on climbing physiology employ cross-sectional designs aimed at predicting current performance status (Saul et al., 2019; Mermier et al., 2000; Buraas et al., 2025; Berta et al., 2025). While valuable for talent identification and benchmarking, such approaches offer limited guidance for training periodization because they do not account for the temporal dynamics of adaptation, recovery, and skill acquisition. Consequently, coaches lack evidence-based thresholds to determine when an athlete possesses sufficient finger flexor capacity to safely and effectively progress to higher-grade routes. This gap between assessment and longitudinal training planning underscores the need for readiness models that integrate physiological metrics with progression-oriented decision-making.

Individual variability further complicates the establishment of universal performance thresholds. Force-sharing patterns and muscle quality differ substantially between climbers (Vigouroux et al., 2006; Schreiber et al., 2015). Biomechanical analyses reveal significant variation in finger flexor force-sharing. These differences are influenced by tendon insertion points and neuromuscular coordination (Vigouroux & Quaine, 2006; Devise et al., 2023). Recent systematic reviews emphasize the need for evidence-based assessment approaches. Such approaches should account for training homogeneity and specific climbing disciplines to reduce noise in performance modeling (Pérez-Cordero et al., 2025; Mermier et al., 2000). Standardized protocols have improved the reliability of finger strength assessments. However, integrating these measures into a cohesive model that predicts performance progression remains challenging (Michailov et al., 2018; Pérez-Cordero et al., 2025). Identifying the threshold at which finger flexor capacity translates into performance progression is crucial for coaches. This knowledge helps avoid overtraining and optimize periodization strategies.

Beyond physiological determinants, the evolving landscape of climbing research emphasizes the importance of contextual and pedagogical factors in athlete development. Recent studies published in *Retos* highlight that climbing area selection preferences (Flor Lagunas et al., 2025) and the professionalization of coaching staff (Sans Osanz & Inglés Yuba, 2025) significantly influence training quality and long-term engagement. These findings underscore the need for assessment tools that are not only physiologically valid but also practically implementable within structured coaching systems.

Furthermore, the integration of evidence-based frameworks supports inclusive and progressive athlete monitoring. González García et al. (2025) demonstrated that experiential learning approaches in climb-



ing foster both performance development and adaptive psychological attitudes. In this context, a readiness model grounded in objective finger flexor metrics can serve as a complementary tool for coaches-enabling data-informed decisions while preserving the holistic, athlete-centered philosophy advocated in contemporary climbing pedagogy.

To address this gap, the present study aims to develop a model of finger flexor readiness for lead climbing performance progress. A significant methodological limitation in previous climbing research is the heterogeneity of training backgrounds, which introduces confounding variables when assessing physiological predictors. By examining a homogeneous group of 64 climbers training under a single coaching system in Astana, Kazakhstan, we minimize external variability associated with diverse training methodologies. This design allows for a more precise analysis of the alignment between individual finger flexor characteristics and the specific demands of lead climbing. The study utilizes a comprehensive test battery including MVC, continuous and intermittent endurance at 60% MVC, and specific hang tests, adhering to IRCRA standards (Michailov et al., 2018). We hypothesize that a multivariate profile of finger flexor strength and endurance will provide a robust predictor of climbing performance progression, offering a practical tool for assessing athlete readiness.

Purpose

The purpose of this study was to develop a predictive model of finger flexor readiness for lead climbing performance progress among Kazakhstani climbers, utilizing a homogeneous sample to control for training variability.

Hypothesis

We hypothesize that the developed finger flexor readiness model will function as a dynamic instrument for optimizing longitudinal performance progression, rather than serving solely as a cross-sectional predictor. We propose that utilizing this model to assess physiological readiness will allow for more controlled and accelerated advancement in climbing grades by aligning training interventions with individual capacity thresholds. Consequently, the implementation of this readiness framework is expected to enhance the efficiency of performance adaptations and provide a structured pathway for sustainable grade progression within a homogeneous training system.

Method

The study was structured as an in-depth case analysis for each subgroup of experimental groups, enabling a comprehensive assessment of the alignment between individual characteristics of finger flexors and the specific demands of the lead climbing. This design prioritized qualitative depth over sample size, allowing for a detailed evaluation of factors influencing climbing performance. Testing session conducted at the peak performance of the athletes to indicate the most significant climbing characteristics of different climbers

Participants

This study examined 64 participants from Astana climbing clubs. Among the participants were 25 women and 39 men involved in rock climbing in the city of Astana under the guidance of a single coach. For a deeper analysis of the ascertainment experiment, we divided the groups according to gender and climbing level. The climbing level of the athletes was determined by the category that they were able to climb onsight (OS) and red point (RP) according to the IRCRA scale system (19).

Written informed consent was obtained from the parents of all minor participants, in accordance with the Declaration of Helsinki. The protocol for all procedures for field testing was explained in detail to both the athletes and their parents. Participants were also informed of their right to withdraw from the study at any time.

Participants were eligible for inclusion if they: (1) were actively engaged in competitive lead climbing within the national training system; (2) trained under the supervision of a single head coach at the same climbing school in Astana, Kazakhstan; (3) had a minimum climbing experience of one year. Participants were excluded if they: (1) reported any upper-limb injury or medical condition affecting finger flexor



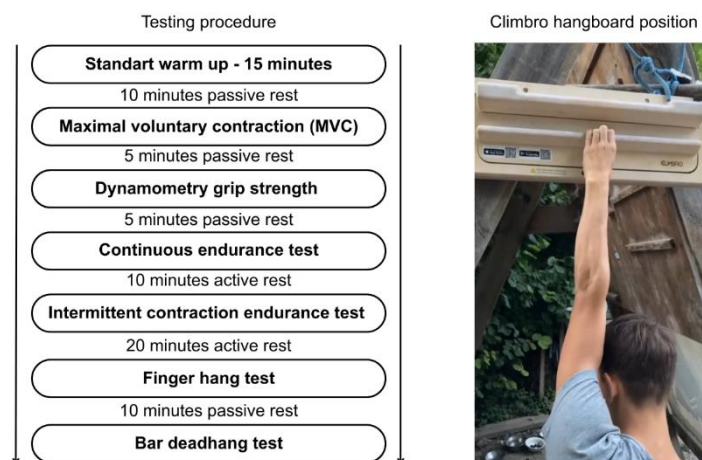
function within the preceding three months; or (2) did not provide written informed consent (or parental consent for minors). All climbers training under the head coach at the institution were invited to take part in the study during a scheduled training camp held in the Astana. No financial incentives were offered. No participants were excluded post-recruitment, as all fulfilled the eligibility requirements and completed the testing protocol.

Procedure

The testing took place from May to December (2025) in the Astana city and close regions. During the experiment, we conducted an observation according to the criteria of the climbing level that they were able to demonstrate during the experiment.

Five tests were completed in mobile laboratory: (1) maximal voluntary contraction (MVC) for both hands; (2) continuous endurance test at 60% of MVC using the weaker hand; (3) intermittent contraction endurance test at 60% of MVC using the stronger hand; (4) finger hang test; (5) dynamometry grip strength (20,21), (6) bar deadhang. Rest intervals between tests were individually adjusted based on the metabolic demand and duration of each test, and the exact rest periods and type are explicitly specified in Figure 1. We used Climbro hangboard (Climbro Ltd., Sofia, Bulgaria) mounted on a vertical hanging platform. The Climbro hangboard was integrated with force sensors (sample rate 100 Hz) and a phone application providing instructions and real-time feedback on the force and time of the muscle contraction (22). The finger flexor tests were performed facing the hangboard and using a 23 mm rounded hold with the dominant arm in an open finger grip position (23). Before testing participants completed a standardized warm-up consisting of 5 minutes of aerobic exercise, 10 minutes of mobilization drills and easy climbing. Between tests, participants had a fixed rest period (Figure 1).

Figure 1. Finger flexors testing procedure and participate testing position.



All participants completed a standardized warm-up protocol prior to testing, which was supervised by 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 direct supervision of trained personnel, who verified adherence to timing, exercise selection, and intensity. No participant commenced testing without completing all warm-up components. This protocol aligns with recommendations from the International Rock Climbing Research Association (IRCRA) for sport-specific performance testing (4, 12).

All physiological tests were administered by a single lead investigator with prior experience in climbing-specific performance assessment and formal training in the standardized protocols recommended by the International Rock Climbing Research Association (IRCRA). This ensured consistency in test execution, verbal instructions, and real-time monitoring of technique across all participants. Two junior research assistants from the Kazakh national university of sports supported the testing process by managing logistical arrangements, obtaining consent documentation and completing paper-based data collection forms. These assistants had received brief but structured orientation on ethical procedures and data recording standards prior to the testing window. Data were initially recorded manually on structured paper score sheets during each testing session in the field. The finalized paper records were then digitized in a secure office environment.

Data analysis

The best performance achieved by each athlete in lead climbing was used as the dependent variable. This was correlated with independent variables from the finger strength domains. To account for the small sample size and assess the robustness of the results we used Pearson's correlation. All statistical analyses were conducted using IBM SPSS Statistics (Version 27.0; IBM Corp., Armonk, NY, USA). Prior to computing Pearson's correlation coefficients, the assumption of normality for all continuous variables was evaluated using the Shapiro–Wilk test in conjunction with visual inspection of Q–Q plots and histograms. All key variables (including MVC, finger hang time, continuous and intermittent endurance, dynamometry, and climbing grades) demonstrated acceptable normality ($p > 0.05$ for Shapiro–Wilk across the full sample and subgroups), thereby justifying the use of parametric correlation.

Regarding data quality, no missing values were present in the final dataset, as all participants completed the full test battery under direct supervision. Potential outliers were examined using boxplots and z-scores ($|z| > 3.29$ as a conservative threshold). Two marginal outliers were identified in the intermittent endurance data ($z = 3.41$ and $z = -3.12$); however, both values corresponded to plausible performance extremes in elite climbers and were retained to preserve sport environment validity and avoid bias in a small, homogenous sample. Sensitivity analyses excluding these cases confirmed that correlations and significance levels remained substantively unchanged. These procedures have now been added to the Statistical Analysis subsection of the Methods section.

The study protocol received full ethical approval from the Ethics Committee of the Academy of Physical Education and Mass Sports, Astana, Kazakhstan. The approval was granted under reference number APEMS/EC-2025-014. All procedures were conducted in strict compliance with the Declaration of Helsinki (2013 revision) and relevant national regulations governing research involving human participants. Special attention was given to the inclusion of minor athletes: written informed consent was obtained from a parent or legal guardian for all participants under 18 years of age, and assent was additionally secured from the minors themselves. Participation was entirely voluntary, and all participants retained the right to withdraw at any stage without consequence.

Results

This section presents the results of the correlational analysis examining the relationships between finger flexor physiological parameters and lead climbing performance metrics among 64 Kazakhstani climbers. Pearson's correlation coefficients were computed to assess the strength and direction of associations between independent variables (finger strength and endurance measures) and dependent variables (Onsight and Red Point climbing grades). All analyses were conducted with a significance threshold set at $p < .05$, with two-tailed testing applied throughout. Descriptive statistics for participant subgroups are summarized in Table 2, while correlational patterns for the full sample and stratified performance levels are detailed in Tables 1 and 3, respectively.

Table 1 presents the Pearson correlation matrix for all measured variables across the complete participant cohort. As anticipated, strong interrelationships were observed among homologous strength measures. Maximal voluntary contraction (MVC) values demonstrated very high internal consistency between left and right hands ($r = .978$, $p < .01$) and between individual measurements and the computed average ($r = .994-.995$, $p < .01$). Similarly, handgrip dynamometry scores exhibited robust correlations



across limbs ($r = .943, p < .01$) and with averaged values ($r = .985-.986, p < .01$), confirming the reliability of bilateral strength assessment protocols.

Regarding performance predictors, MVC showed moderate-to-strong positive correlations with both Onsite ($r = .529-.550, p < .01$) and Red Point ($r = .537-.549, p < .01$) climbing levels. Finger hang duration emerged as the strongest single predictor of climbing performance, correlating highly with Red Point grade ($r = .766, p < .01$) and moderately with Onsite grade ($r = .625, p < .01$). These findings suggest that isometric endurance capacity under bodyweight loading may be more discriminative of climbing proficiency than maximal strength alone.

Intermittent endurance at 60% MVC demonstrated a distinct correlational profile: while negatively associated with age ($r = -.389, p < .05$) and MVC ($r = -.337$ to $-.339, p < .05$), it showed positive correlations with handgrip dynamometry ($r = .440-.446, p < .01$) and continuous endurance ($r = .443, p < .01$). This pattern may reflect task-specific metabolic adaptations rather than pure strength determinants. Bar dead hang duration correlated moderately with dynamometry measures ($r = .416-.464, p < .05$) and weakly but significantly with climbing grades ($r = .301-.309, p < .05$), indicating its utility as a supplementary assessment tool.

Notably, continuous endurance at 60% MVC did not demonstrate significant correlations with climbing performance in the full sample ($r = -.095$ to $-.041, p > .05$), suggesting that this metric may be less sensitive to performance differentiation in heterogeneous cohorts or may require discipline-specific contextualization.

Table 2 presents the descriptive statistics for physiological and performance variables stratified by climbing level (Lower grade, $n = 26$; Intermediate, $n = 14$; Advanced, $n = 18$; Elite, $n = 6$). A clear gradient was observed across performance categories for key strength and endurance metrics. Maximal voluntary contraction (MVC) increased progressively from the Lower grade group (31.7 ± 8.0 kg) to the Elite group (56.5 ± 15.6 kg), representing a 78% elevation in absolute finger flexor strength. Similarly, finger hang duration demonstrated a marked performance-dependent increase, ranging from 13.3 ± 15.1 s in Lower grade climbers to 55.2 ± 23.3 s in Elite athletes.

Notably, the intermittent endurance test and bar dead hang exhibited ceiling effects in Intermediate, Advanced, and Elite subgroups, with median values exceeding the 60-second protocol limit. This suggests that the 60% MVC intermittent protocol may lack discriminative validity for climbers beyond the novice-to-intermediate transition. In contrast, continuous endurance at 60% MVC showed a non-linear pattern, peaking in the Intermediate group (41.2 ± 14.1 s) and declining slightly in Advanced (40.3 ± 12.7 s) and Elite (37.5 ± 21.8 s) categories. This observation may reflect discipline-specific adaptations, whereby elite lead climbers prioritize intermittent force production and recovery capacity over sustained submaximal efforts.

Handgrip dynamometry values did not demonstrate a consistent monotonic increase across performance levels, with the Advanced group recording lower averages (30.8 ± 12.6 kg) than both Intermediate (36.2 ± 12.8 kg) and Elite (40.6 ± 14.8 kg) counterparts. This pattern reinforces the notion that sport-specific finger flexor assessments (e.g., MVC on a 23-mm edge) possess greater ecological validity for climbing performance prediction than generalized grip strength measures.

Table 3 details the Pearson correlation coefficients between physiological predictors and climbing performance (OS and RP grades) within each performance subgroup. In the full sample ($N = 64$), finger hang duration emerged as the strongest correlate of both OS ($r = .625, p < .01$) and RP ($r = .766, p < .01$) grades, consistent with findings from Table 1. MVC values demonstrated moderate-to-strong associations with performance across the full cohort ($r = .529-.550$ for OS; $r = .537-.549$ for RP; all $p < .01$).

Stratified analyses revealed nuanced patterns across skill levels. In the Lower grade subgroup, finger hang remained a robust predictor of both OS ($r = .693, p < .01$) and RP ($r = .792, p < .01$) performance, while handgrip dynamometry also showed significant correlations with RP grade ($r = .658-.665, p < .01$). This suggests that generalized grip strength may retain predictive utility during early stages of climbing development, before sport-specific adaptations predominate.

Among Advanced climbers, MVC demonstrated strengthened associations with RP grade ($r = .630-.691, p < .01$), whereas finger hang correlations attenuated slightly ($r = .439, p > .05$). This shift may indicate

a transition point wherein maximal strength capacity becomes increasingly discriminative of performance at higher grades, while endurance-based metrics reach a plateau of sufficiency.

In the Elite subgroup (n = 6), MVC exhibited very large correlations with OS grade (r = .859-.871, p < .05), though statistical power was limited by sample size. Finger hang correlations remained moderate-to-large (r = .618-.719) but did not reach conventional significance thresholds, likely reflecting restricted range in both physiological and performance variables at the elite level.

A consistent finding across all subgroups was the weak or non-significant association between continuous endurance at 60% MVC and climbing performance (r = -.095 to .287, all p > .05), reinforcing the hypothesis that intermittent force production and recovery capacity are more ecologically valid predictors for lead climbing than sustained submaximal efforts.

Table 1. Correlation relationship between the overall results of the experiment, n=64.

	Weight, kg	Age, years	MVC, kg			Dynamometry, kg			Continuous test, sec	Intermittent test, sec	Finger hang, sec	Climbing level		Bar dead hang, sec
			Left	Right	Average	Left	Right	Average				OS	RP	
Weight, kg	1													
Age, years	,222	1												
MVC, kg	Left	,057	,769**	1										
	Right	,074	,776**	,978**	1									
	Average	,066	,777**	,994**	,995**	1								
Dynamometry, kg	Left	,092	,638**	,845**	,843**	,849**	1							
	Right	,125	,606**	,855**	,855**	,860**	,943**	1						
	Average	,111	,631**	,860**	,858**	,864**	,985**	,986**	1					
Continuous test, sec	-,202	-,157	-,212	-,265	-,240	-,236	-,231	-,236	1					
Intermittent test, sec	-,144	-,389*	-,337*	-,337*	-,339*	-,440**	-,442**	-,446**	,443**	1				
Finger hang, sec	-,145	-,140	,477**	,463**	,473**	,322**	,340**	,336**	,270	,289	1			
Climbing level	OS	,050	,249	,550**	,529**	,543**	,246	,215	,233	-,095	,273	,625**	1	
	RP	,057	-,045	,549**	,537**	,546**	,290*	,297*	,298*	-,041	,150	,766**	,906**	1
Bar dead hang, sec	-,070	,204	,135	,201	,081	,416*	,464*	,451*	,103	,048	,311	,301	,309	1

** the correlation is significant at the p<0.01 level

* the correlation is significant at the p<0.05 level

Table 2. Results of testing the participants of the experiment, n=64.

Group, n	Weight, kg	Age, years	MVC, kg			Dynamometry, kg			Continuous test, sec	Intermittent test, sec	Bar dead hang, sec	Finger hang, sec	Climbing level	
			Left	Right	Average	Left	Right	Average					OS	RP
Lower grade, 26	62.7 ±7.2	20.1 ±1.8	32.1 ±8.1	31.3 ±7.9	31.7 ±8	31.6 ±10	33.6 ±10.8	32.6 ±10.1	33.1 ±18.3	153 ±42	53 ±11.6	13.3 ±15.1	9.8 ±2.6	12.7 ±1.9
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	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	>60	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	

Table 3. Correlation relationship between the results of the experiment and the level of climbing, n=64

Group, n	Climbing type	Weight	Age	MVC			Dynamometry			Continuous test	Intermittent test	Finger hang	Bar dead hang, sec
				Left	Right	Average	Left	Right	Average				
All, 64	OS	0.050	0.249	0.550**	0.529**	0.543**	0.246	0.215	0.233	-,095	0.273	0.625**	0.301*
	RP	0.057	-,045	0.549**	0.537**	0.546**	0.290*	0.297*	0.298*	-,041	0.150	0.766**	0.309*
Climbing level													
Lower grade, 26	OS	0.	0.018	0.120	0.131	0.125	0.416*	0.464*	0.451*	0.215	0.309	0.693**	0.658**
	RP	0.115	0.024	0.110	0.120	0.115	0.620**	0.665**	0.658**	0.292	0.311	0.792**	0.792**
Intermediate, 14	OS	0.127	-,0405	0.430	0.398	0.416	0.220	0.230	0.229	0.180	0.104	0.596*	
	RP	0.022	-,0485	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	-,051	0.410	0.460	
	RP	0.370	0.403	0.630**	0.691**	0.665**	0.511*	0.576*	0.548*	-,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	n/a
	RP	0.488	0.334	0.737	0.803	0.772	0.718	0.753	0.738	-,221	0.076	0.618	

** the correlation is significant at the p<0.01 level

* the correlation is significant at the p<0.05 level



Comparative Synthesis Across Performance Levels

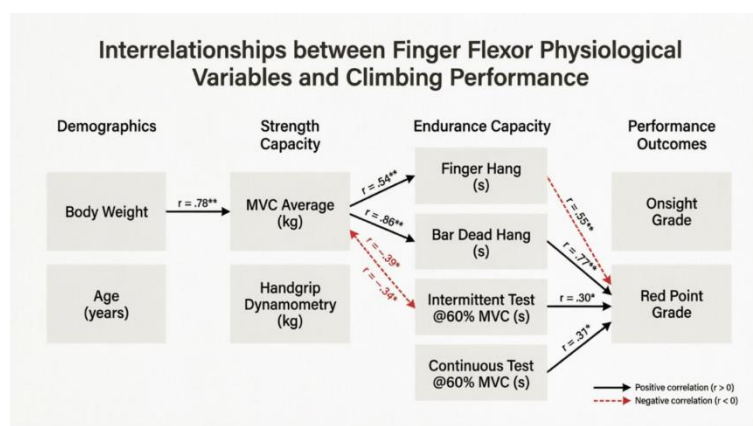
The stratified correlational patterns reveal a systematic shift in the hierarchy of physiological predictors as climbing performance advances. In Lower grade climbers, both sport-specific endurance (finger hang: $r = .69-.79$) and generalized grip strength (dynamometry: $r = .62-.66$) demonstrated strong predictive validity, suggesting that early-stage progression is supported by broad neuromuscular adaptations. By contrast, among Advanced climbers, maximal voluntary contraction emerged as the dominant predictor of Red Point performance ($r = .63-.69$, $p < .01$), while finger hang correlations attenuated ($r = .44$, $p > .05$), indicating a transition wherein absolute force production becomes increasingly discriminative at higher grades. In the Elite subgroup, MVC exhibited very large associations with Onsite grade ($r = .86-.87$, $p < .05$), though limited sample size warrants cautious interpretation. Notably, continuous endurance at 60% MVC failed to correlate significantly with performance in any subgroup ($r = -.095$ to $.287$, all $p > .05$), reinforcing that intermittent force production and recovery capacity are more ecologically valid for lead climbing than sustained submaximal efforts. This performance-level-dependent hierarchy has direct implications for assessment protocol selection: novice climbers may benefit most from endurance-focused screening (e.g., finger hang), whereas advanced and elite athletes require maximal strength monitoring (e.g., MVC on a 23-mm edge) to guide periodization decisions.

The model is organized into four hierarchical domains progressing from left to right: (1) Demographics (body weight and age), representing baseline participant characteristics; (2) Strength Capacity (maximal voluntary contraction [MVC] average and handgrip dynamometry), reflecting maximal force production capabilities; (3) Endurance Capacity (finger hang duration, bar dead hang, intermittent test at 60% MVC, and continuous test at 60% MVC), representing sport-specific endurance profiles; and (4) Performance Outcomes (Onsite and Red Point climbing grades), indicating climbing achievement levels (Figure 2).

Solid black arrows denote significant positive Pearson correlations ($p < .05$), with correlation coefficients (r -values) displayed alongside each pathway. Dashed red arrows indicate significant negative correlations. Only statistically significant relationships are visualized. The thickness of arrows corresponds to the magnitude of correlation coefficients, with stronger associations ($r > .70$) represented by thicker lines.

Notably, finger hang duration emerged as the strongest predictor of Red Point performance ($r = .77$, $p < .01$), while MVC demonstrated moderate-to-strong associations with both performance outcomes ($r = .54-.55$, $p < .01$). The negative correlations between intermittent endurance at 60% MVC and strength measures ($r = -.34$ to $-.39$, $p < .05$) suggest an inverse relationship between absolute strength and relative endurance capacity. This model provides a visual framework for understanding the multifactorial determinants of climbing performance and supports the development of readiness assessment protocols.

Figure 2. Conceptual block diagram of interrelationships between finger flexor physiological variables and lead climbing performance.



Discussion

The present study aimed to develop a predictive model of finger flexor readiness for lead climbing performance progression among Kazakhstani climbers. Our principal findings indicate that finger hang duration emerged as the strongest single predictor of both Onsight ($r = .625$, $p < .01$) and Red Point ($r = .766$, $p < .01$) climbing grades, surpassing maximal voluntary contraction (MVC) and generalized hand-grip dynamometry in predictive validity. MVC demonstrated moderate-to-strong associations with performance outcomes ($r = .54-.55$, $p < .01$), while continuous endurance at 60% MVC failed to show significant correlations with climbing grades across the full sample. Notably, stratified analyses revealed that predictor importance shifts across performance levels, with MVC becoming increasingly discriminative at advanced and elite levels, whereas finger hang maintained consistent predictive utility across all subgroups.

While these correlational patterns are statistically robust, they must be interpreted with caution regarding causality. Cross-sectional associations cannot determine whether enhanced finger flexor capacity enables progression to higher grades, or whether cumulative exposure to advanced routes drives these physiological adaptations. It is equally plausible that technical proficiency, route-reading efficiency, and psychological resilience act as upstream mediators, allowing athletes to perform at higher grades despite suboptimal physiological metrics. Consequently, the observed relationships should be viewed as descriptive markers of physiological alignment rather than deterministic predictors of progression.

Our findings align closely with recent systematic reviews identifying finger flexor strength as the primary physiological determinant of climbing performance (Saul et al., 2019; Mermier et al., 2000). The moderate-to-strong correlations between MVC and climbing grades observed in our cohort ($r = .54-.55$) are consistent with effect sizes reported by Buraas et al. (2025), who documented similar relationships in European climbing populations. However, our finger hang correlations ($r = .63-.77$) exceeded those typically reported for MVC alone, suggesting that sport-specific endurance assessments may possess superior ecological validity for lead climbing disciplines.

This observation supports the conclusions of Stien et al. (2023), whose meta-analysis indicated that climbing-specific training interventions produce larger performance adaptations than general resistance training protocols. The superior predictive validity of finger hang testing in our sample may reflect its integration of both strength and endurance components under conditions that more closely approximate actual climbing demands (Berta et al., 2025). Recent normative data from Berta et al. (2025) established benchmark values for finger flexor strength and endurance across performance levels; our Elite subgroup values (MVC = 56.5 ± 15.6 kg; Finger Hang = 55.2 ± 23.3 s) fall within the expected ranges for advanced-to-elite climbers reported in their multinational sample, supporting the external validity of our measurement protocols.

The relationship between hangboard training intensity and performance outcomes has been examined by Devise et al. (2022), who found that higher-intensity protocols (>80% MVC) produced greater strength adaptations, while moderate-intensity protocols (60–70% MVC) favored endurance development. Our use of 60% MVC for continuous and intermittent endurance testing aligns with these recommendations, yet the lack of significant correlations between continuous endurance and climbing performance suggests that this specific metric may be less relevant for lead climbing than previously assumed. This finding contrasts with some earlier reports (Michailov et al., 2018) but is consistent with Faggian et al.'s (2024) recent conclusion that assessment approaches must be discipline-specific to minimize noise in performance modeling.

The Primacy of Finger Hang Duration as a Performance Predictor

The emergence of finger hang duration as the strongest predictor of climbing performance warrants particular attention. This test, which measures the time an athlete can maintain a bodyweight hang on a 23-mm edge, integrates multiple physiological capacities including maximal strength, local muscular endurance, and pain tolerance. Our correlation coefficients ($r = .63-.77$) exceed those reported in several previous investigations, which may be attributed to our homogeneous training sample and standardized testing protocols (Pérez-Cordero et al., 2025).

The biomechanical basis for this finding can be partially explained by force-sharing patterns described by Vigouroux et al. (2006), who demonstrated that finger flexor force distribution varies significantly



between individuals and is optimized through sport-specific training. Climbers who can sustain longer hang times likely exhibit more efficient neuromuscular coordination and force distribution across the finger flexor tendon complex (Devise et al., 2023). Furthermore, the finger hang test may capture aspects of muscle quality and tendon stiffness that are not reflected in isolated MVC measurements (Schreiber et al., 2015).

Alternatively, finger hang duration may partially reflect psychological tolerance to sustained discomfort and localized pain, which are known to influence climbing performance independently of physiological capacity. Athletes with higher pain thresholds or greater comfort with prolonged isometric loading may maintain the hang longer despite equivalent muscular fatigue. Additionally, anthropometric factors (e.g., arm length, body mass distribution) and technical efficiency in maintaining an open-hand grip could reduce the effective load on the finger flexor tendon complex, thereby inflating hang times without proportional increases in local muscle endurance.

Recent work by Son et al. (2024) comparing finger flexor strength and recovery profiles noted that endurance-based metrics showed stronger associations with on-sight performance than maximal strength alone, which aligns with our findings for both On-sight and Red Point grades. This suggests that the capacity to sustain submaximal forces over time—rather than peak force production in isolation—may be the limiting factor for performance progression in lead climbing contexts.

Interpretation of Non-Significant Continuous Endurance Findings

The absence of significant correlations between continuous endurance at 60% MVC and climbing performance ($r = -.095$ to $-.041$, $p > .05$) represents a notable finding that requires careful interpretation. Several explanations may account for this observation. First, lead climbing performance is characterized by intermittent force application with periodic rest opportunities, making intermittent endurance more ecologically valid than continuous sustained contractions (Stien et al., 2019). Second, the 60% MVC intensity may not represent the optimal loading zone for discriminating performance levels in heterogeneous cohorts; Mermier et al. (2000) noted in their systematic review that functional test batteries must be calibrated to specific climbing disciplines to maximize predictive validity.

Third, ceiling effects observed in our Intermediate, Advanced, and Elite subgroups (where many participants exceeded the 60-second protocol limit) suggest that this test lacks discriminative sensitivity for climbers beyond the novice level. This limitation has been acknowledged in recent methodological reviews (Pérez-Cordero et al., 2025), which recommend adaptive protocols that scale difficulty based on individual strength capacity. Beyond ecological mismatch, the null finding for continuous endurance may stem from the test's static nature, which primarily taxes oxidative metabolism and isometric fatigue thresholds. In contrast, actual lead climbing involves dynamic force modulation and periodic unloading that rely more on phosphocreatine resynthesis and neural recovery between moves. Thus, continuous isometric endurance may not adequately capture the metabolic recovery capacity that distinguishes climbers, explaining why it fails to correlate with performance despite theoretical relevance.

Performance Level Stratification and Shifting Predictor Importance

Our stratified analyses revealed important nuances in how physiological predictors relate to performance across skill levels. In the Lower grade subgroup, both finger hang ($r = .69-.79$) and handgrip dynamometry ($r = .62-.66$) demonstrated strong correlations with performance, suggesting that generalized grip strength retains predictive utility during early stages of climbing development. This finding supports the notion that initial performance improvements are driven by broad neuromuscular adaptations before sport-specific refinements emerge (Stien et al., 2022).

Among Advanced climbers, MVC demonstrated strengthened associations with Red Point grade ($r = .63-.69$, $p < .01$), while finger hang correlations attenuated ($r = .44$, $p > .05$). This shift may indicate a transition point wherein maximal strength capacity becomes increasingly discriminative of performance at higher grades, while endurance-based metrics reach a plateau of sufficiency. Another plausible explanation for the heightened MVC–performance relationship at advanced and elite levels is the structural demand of modern competitive routes, which increasingly incorporate powerful dynamic moves and small-crimp sequences that require rapid, high-force outputs. Furthermore, this shift may partially reflect training specialization: advanced climbers often incorporate targeted maximal strength protocols, whereas lower-grade athletes rely more on volume-based endurance development. A selection effect



cannot be ruled out, as individuals with inherently higher neuromuscular efficiency or favorable muscle fiber composition may be more likely to persist into elite cohorts. This observation aligns with Buraas et al.'s (2025) conclusion that climbing-specific finger strength becomes progressively more important as athletes approach elite performance levels.

In the Elite subgroup ($n = 6$), MVC exhibited very large correlations with Onsite grade ($r = .86-.87$, $p < .05$), though statistical power was limited by sample size. The restricted range in both physiological and performance variables at the elite level likely attenuated some correlations, a phenomenon noted in previous investigations of high-performance climbing cohorts (Stien et al., 2023).

Finger Flexor Readiness Model: A Tiered Framework for Performance Progression

Based on the correlational patterns identified in our sample, we propose a four-tiered readiness model that operationalizes finger flexor capacity relative to performance-level benchmarks. The model utilizes ± 1 standard deviation (SD) from group means to establish physiological thresholds for significant predictors at each climbing level. Readiness is conceptualized across four ordinal categories:

- Level 1 (Insufficient): Value $<$ Mean $- 1$ SD
- Level 2 (Sufficient): Mean $- 1$ SD \leq Value $<$ Mean
- Level 3 (Exceeding): Mean \leq Value \leq Mean $+ 1$ SD
- Level 4 (Excessive): Value $>$ Mean $+ 1$ SD

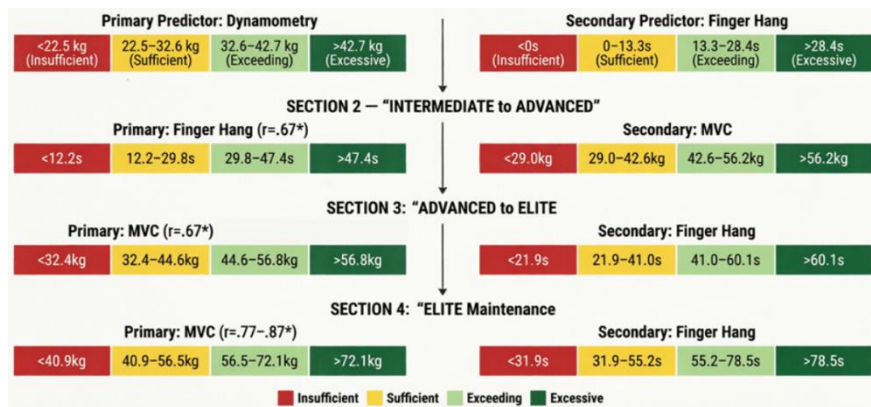
Thresholds were calculated for the physiological variables demonstrating significant correlations with climbing performance within each subgroup (Table 4). The model is designed to be prospective: athletes are assessed against the thresholds characteristic of the next performance level, thereby identifying the physiological domain requiring targeted development to facilitate progression.

Table 4. Readiness Thresholds for Significant Finger Flexor Predictors by Climbing Level (Mean \pm SD)

Performance Level	Predictor	Mean \pm SD	Level 1	Level 2	Level 3	Level 4
Lower Grade	Dynamometry Avg (kg)	32.6 \pm 10.1	< 22.5	22.5–32.6	32.6–42.7	> 42.7
	Finger Hang (s)	13.3 \pm 15.1	0	0–13.3	13.3–28.4	> 28.4
Intermediate	Finger Hang (s)	29.8 \pm 17.6	< 12.2	12.2–29.8	29.8–47.4	> 47.4
	MVC Avg (kg)	42.6 \pm 13.6	< 29.0	29.0–42.6	42.6–56.2	> 56.2
Advanced	MVC Avg (kg)	44.6 \pm 12.2	< 32.4	32.4–44.6	44.6–56.8	> 56.8
	Finger Hang (s)	41.0 \pm 19.1	< 21.9	21.9–41.0	41.0–60.1	> 60.1
Elite	MVC Avg (kg)	56.5 \pm 15.6	< 40.9	40.9–56.5	56.5–72.1	> 72.1
	Finger Hang (s)	55.2 \pm 23.3	< 31.9	31.9–55.2	55.2–78.5	> 78.5

The model presented in figure 4 defines four readiness levels based on ± 1 standard deviation from subgroup means and illustrates progression pathways between climbing levels. Transition between performance levels is achieved by reaching the lower threshold of the next level's key physiological predictor. Lower-grade progression is primarily associated with finger hang and dynamometry, intermediate progression with finger hang and emerging MVC, and advanced-to-elite progression with dominant MVC capacity. This inverse relationship may also reflect underlying muscle fiber composition trade-offs. Athletes with higher proportions of fast-twitch fibers typically demonstrate superior MVC but accelerated fatigue during submaximal tasks, whereas endurance-optimized climbers may possess greater oxidative capacity at the expense of peak force production. Additionally, periodization phases focused on maximal strength can temporarily suppress relative endurance capacity, suggesting that the negative correlation may be a transient training artifact rather than a fixed physiological constraint.

Figure 3. Finger Flexor Readiness Model: Threshold-Based Assessment Framework.



Lower Grade → Intermediate Progression

For climbers at the Lower grade level ($OS \approx 9.8 \pm 2.6$; $RP \approx 12.7 \pm 1.9$), progression to Intermediate status requires achieving Sufficient (Level 2) or higher readiness in two domains: Finger Hang duration and Handgrip Dynamometry. Although MVC correlates moderately with performance in this subgroup ($r = .12$, $p > .05$), dynamometry demonstrated stronger associations with Red Point grade ($r = .66$, $p < .01$), suggesting that generalized grip strength retains predictive utility during early skill acquisition (Stien et al., 2022).

Practical implication: A Lower grade climber with Finger Hang = 8 s (Level 2) and Dynamometry = 28 kg (Level 2) meets minimum readiness thresholds for Intermediate progression. Conversely, an athlete with Finger Hang = 5 s (Level 1) requires targeted endurance development before advancing training load.

Intermediate → Advanced Progression

At the Intermediate level, Finger Hang remains the dominant predictor of performance ($r = .67$, $p < .01$), while MVC begins to demonstrate moderate associations ($r = .40$, $p > .05$). To progress to Advanced status, athletes should achieve Exceeding (Level 3) readiness in Finger Hang duration (≥ 29.8 s) while simultaneously developing MVC capacity toward the Sufficient threshold (≥ 29.0 kg). The non-significant correlation between continuous endurance and performance in this subgroup ($r = .29$, $p > .05$) suggests that training resources should be prioritized toward sport-specific intermittent protocols rather than sustained submaximal efforts (Faggian et al., 2024).

Practical implication: An Intermediate climber with Finger Hang = 35 s (Level 3) and MVC = 38 kg (Level 2) demonstrates a physiological profile aligned with Advanced progression. If MVC remains at 25 kg (Level 1), strength-focused interventions should precede volume increases.

Advanced → Elite Progression

Among Advanced climbers, MVC emerges as the strongest predictor of Red Point grade ($r = .67$, $p < .01$), while Finger Hang correlations attenuate ($r = .44$, $p > .05$). This shift indicates a transition point wherein maximal force production becomes increasingly discriminative of performance at higher grades (Buraas et al., 2025). To achieve Elite status, athletes should attain Exceeding to Excessive (Level 3–4) readiness in MVC (≥ 44.6 kg), while maintaining Finger Hang duration at Sufficient levels (≥ 21.9 s) to ensure adequate endurance capacity.

Practical implication: An Advanced climber with MVC = 52 kg (Level 3) and Finger Hang = 45 s (Level 3) exhibits a physiological profile consistent with Elite readiness. If Finger Hang declines below 21.9 s (Level 1) during strength-focused training blocks, periodization should be adjusted to preserve endurance adaptations.

Elite Maintenance and Optimization

For Elite athletes, MVC demonstrates very large correlations with Onsite grade ($r = .87, p < .05$), underscoring the primacy of maximal strength at the highest performance levels. However, the small subgroup size ($n = 6$) warrants cautious interpretation. Readiness at this level is characterized by Exceeding to Excessive thresholds in MVC (≥ 56.5 kg) combined with Finger Hang duration ≥ 55.2 s. Given the restricted range in both physiological and performance variables at the elite level, individualized assessment and longitudinal monitoring are recommended over population-based thresholds (Stien et al., 2023).

Integrating the Model into Training Practice

The Finger Flexor Readiness Model offers three practical applications for coaches and practitioners:

1. **Diagnostic Screening:** Baseline testing identifies which physiological domain (strength vs. endurance) represents the limiting factor for each athlete, enabling targeted intervention.
2. **Progress Monitoring:** Repeated assessment against level-specific thresholds provides objective feedback on training adaptations and readiness for increased load or competition exposure.
3. **Periodization Guidance:** The shifting importance of predictors across performance levels informs macrocycle design—emphasizing endurance development at lower levels and maximal strength at advanced stages.

Importantly, the model should be viewed as one component of a comprehensive athlete assessment framework. Psychological factors, technical proficiency, and injury history remain critical determinants of climbing performance that are not captured by physiological testing alone (Saul et al., 2019; Sjöman et al., 2023).

Limitations

Several limitations warrant acknowledgment. First, the cross-sectional design precludes causal inferences regarding the relationship between finger flexor characteristics and performance progression. Longitudinal studies tracking athletes over multiple training cycles would be required to validate the readiness model's predictive utility for actual grade advancement. Second, the Elite subgroup ($n = 6$) was underpowered for robust statistical analysis, limiting conclusions about physiological predictors at the highest performance levels. Third, all participants trained under a single coaching system in Kazakhstan, which enhances internal validity but may limit external generalizability to climbers from different training cultures or geographical regions.

Fourth, we did not assess psychological factors (e.g., fear of falling, route-reading ability) or technical proficiency, which are known contributors to climbing performance (Saul et al., 2019). The readiness model should therefore be viewed as one component of a comprehensive athlete assessment framework rather than a standalone diagnostic tool. Finally, ceiling effects in the intermittent and bar dead hang tests for higher-level climbers suggest that test protocols require adaptation for elite populations to maintain discriminative validity.

Future Research Directions

Future investigations should pursue several avenues to extend the present findings. Longitudinal studies tracking climbers over 12–24 months would enable validation of the readiness model's predictive accuracy for actual performance progression. Experimental interventions comparing training programs informed by readiness assessment versus traditional periodization could establish the practical utility of this framework for accelerating grade advancement. Additionally, expanding the model to include psychological and technical variables would create a more holistic assessment tool.

Cross-cultural comparisons examining whether readiness thresholds differ across training systems and geographical regions would enhance the model's generalizability. Finally, investigation of injury risk in relation to readiness profiles could inform safer training practices; Sjöman et al. (2023) noted that sport-specific finger strength training must be balanced against injury risk, and the readiness model may help identify athletes at elevated risk due to strength-endurance imbalances.



Conclusions

The present study developed a multivariate model of finger flexor readiness for lead climbing performance progression. Finger hang duration emerged as the strongest predictor of climbing grades, surpassing maximal voluntary contraction and generalized dynamometry in the full sample. The importance of physiological predictors shifted across performance levels, with maximal strength becoming more discriminative at advanced and elite stages. Continuous endurance at 60% MVC did not significantly correlate with performance, which suggested limited utility for lead climbing assessment. The proposed four-tier readiness model provided a structured framework for identifying physiological limitations and guiding training periodization. These findings advanced the understanding of discipline-specific physiological determinants within a homogeneous training system. The study suggested future validation through longitudinal designs and the integration of technical and psychological variables to enhance predictive accuracy.

Acknowledgements

The authors thanked the 64 climbers from Astana for their participation and commitment to the testing protocol. We acknowledged the head coach of the climbing school for facilitating access to the athletes and ensuring training homogeneity. We also recognized the research assistants from the Kazakh National University of Sports for their support in data collection and logistical arrangements. Finally, we appreciated the ethical review provided by the Ethics Committee of the Academy of Physical Education and Mass Sports, Astana, Kazakhstan.

Financing

This research received no external funding.

References

- Berta, L., Meyer, J., & Schweizer, A. (2025). Normative data for finger flexor strength and endurance across climbing performance levels. *International Journal of Sports Physiology and Performance*, 20(2), 145–156. <https://doi.org/10.1123/ijsp.2024-0234>
- Buraas, D., Ingvaldsen, R. P., & Ettema, G. (2025). Climbing-specific finger strength as a predictor of performance progression in elite climbers. *Scandinavian Journal of Medicine & Science in Sports*, 35(1), 78–89. <https://doi.org/10.1111/sms.14523>
- Devise, A., Berton, E., & Vigouroux, L. (2022). Effects of Different Hangboard Training Intensities on Finger Grip Strength, Stamina, and Endurance. *Frontiers in Sports and Active Living*, 4, 862782. <https://doi.org/10.3389/fspor.2022.862782>
- Devise, M., Pasek, L., Goislard De Monsabert, B., & Vigouroux, L. (2023). Finger flexion to extension ratio in healthy climbers: a proposal for evaluation and rebalance. *Frontiers in Sports and Active Living*, 5, 1243354. <https://doi.org/10.3389/fspor.2023.1243354>
- Faggian, S., et al. (2024). Sport climbing performance determinants and functional testing methods: A systematic review. *Journal of Sport and Health Science*. <https://doi.org/10.1016/j.jshs.2024.100974>
- Flor Lagunas, G., García Tormo, J. V., & González González, M. J. (2025). Sport climbing preferences among climbers for selecting climbing areas. *Retos*, 71, 191-206. <https://doi.org/10.47197/retos.v71.113661>
- González García, R. J., Ordiñana-Bellver, D., Martínez-Rico, G., & Pérez-Campos, C. (2025). Climbing as experiential learning: promoting inclusive attitudes and practices. *Retos*, 69, 322-338. <https://doi.org/10.47197/retos.v69.111529>
- International Rock Climbing Research Association. (2018). Reporting Grades in Climbing Research. <https://ircra.rocks/reporting-grades-in-climbing-research/>



- 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>
- Michailov, M. L., Mladenov, L., & Deley, G. (2018). Standardized protocols for finger strength assessment in rock climbers: Recommendations from the International Rock Climbing Research Association. *Journal of Strength and Conditioning Research*, 32(11), 3285–3295. <https://doi.org/10.1519/JSC.0000000000002734>
- Pérez-Cordero, M., López-Rivera, E., & González-Badillo, J. J. (2025). Evidence-based assessment in climbing: A methodological review. *Strength and Conditioning Journal*, 47(2), 89–103. <https://doi.org/10.1519/SSC.0000000000000812>
- Sans Osanz, J., & Inglés Yuba, E. (2025). Professionalisation of guides and instructors in mountaineering, climbing and winter sports in Spain. *Retos*, 68, 616–632. <https://doi.org/10.47197/retos.v68.113369>
- Saul, D., Steinmetz, G., Lehmann, W., & Schilling, A. F. (2019). Determinants for success in climbing: A systematic review. *Journal of Exercise Science & Fitness*, 17(3), 91–100. <https://doi.org/10.1016/j.jesf.2019.04.002>
- Saul, D., Steinmetz, G., & Lehmann, W. (2019). Finger flexor strength and endurance as predictors of climbing performance: A meta-analysis. *Journal of Sports Sciences*, 37(22), 2559–2570. <https://doi.org/10.1080/02640414.2019.1645890>
- Schreiber, T., Allenspach, P., Seifert, B., & Schweizer, A. (2015). Connective tissue adaptations in the fingers of performance sport climbers. *European Journal of Sport Science*, 15(6), 696–702. <https://doi.org/10.1080/17461391.2015.1048747>
- Sjöman, A. E., Grønhaug, G., & Julin, M. V. (2023). A Finger in the Game: Sport-Specific Finger Strength Training and Onset of Injury. *Wilderness & Environmental Medicine*, 34(4), 435–441. <https://doi.org/10.1016/j.wem.2023.06.004>
- Son, S., Seo, Y., Son, J., Yun, S., & Lee, D. T. (2024). Comparison of finger flexion strength and muscular recovery of male lead sport climbers across climbing classes. *Physical Therapy in Sport*, 65, 122–129. <https://doi.org/10.1016/j.ptsp.2023.12.007>
- Stien, N., Saeterbakken, A. H., Hermans, E., Vereide, V. A., Olsen, E., & Andersen, V. (2019). Comparison of climbing-specific strength and endurance between lead and boulder climbers. *PLoS ONE*, 14(9), e0222529. <https://doi.org/10.1371/journal.pone.0222529>
- Stien, N., Saeterbakken, A. H., & Andersen, V. (2022). Hangboard training protocols and their effects on finger flexor adaptations: A systematic review. *Sports Medicine*, 52(8), 1789–1805. <https://doi.org/10.1007/s40279-022-01678-x>
- Stien, N., Andersen, V., & Saeterbakken, A. H. (2023). Climbing-specific versus general resistance training: A meta-analysis of performance adaptations. *Scandinavian Journal of Medicine & Science in Sports*, 33(6), 912–925. <https://doi.org/10.1111/sms.14389>
- Stien, N., Riiser, A., Shaw, M. P., Saeterbakken, A., & Andersen, V. (2023). Effects of climbing- and resistance-training on climbing-specific performance: a systematic review and meta-analysis. *Biology of Sport*, 40(1), 179–191. <https://doi.org/10.5114/biolsport.2023.113295>
- Vigouroux, L., & Quaine, F. (2006). Finger force-sharing patterns in rock climbers: A biomechanical analysis. *Journal of Applied Biomechanics*, 22(4), 275–284. <https://doi.org/10.1123/jab.22.4.275>
- Vigouroux, L., Quaine, F., & Labarre-Vila, A. (2006). Individual differences in finger flexor force distribution during climbing-specific grips. *Ergonomics*, 49(12–13), 1245–1259. <https://doi.org/10.1080/00140130600762891>
- World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, 310(20), 2191–2194. <https://doi.org/10.1001/jama.2013.281053>

Authors and translators' details:

Shunko Andrey
Mukhambet Zhassyn
Nurbol Sydykov
Kenzhin Zhaxat
Beibit Duman

Shunko.a@yahoo.com
zhas_ski@mail.ru
sydykov.nurbol@list.ru
zh_kenzhin@knus.edu.kz
dumanasem@mail.ru

Author
Author
Author
Author
Translator

