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The relationship between upper-body and lower-body power with speed climbing performance in bandung city athletes: a correlational study

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ABSTRACT

On a typical 15-meter-high wall with a 5° overhang, world-record-level speed climbing requires incredibly quick, explosive, and effective vertical motion. Biomechanical power components, especially upper-body and lower-body power, are important factors that determine athletic performance, as seen by the pattern of world records showing a considerable and constant decrease in time. However, there is still a dearth of research that particularly examines the connection between these two elements in athletes competing at the national level in speed climbing. The purpose of this study is to examine how speed climbing athletes in the world record category perform in relation to upper-body power, lower-body power, and their combination. All speed climbing athletes from the Bandung City FPTI (n=14, total sampling technique) were subjected to a quantitative approach using a correlational design. The medicine ball chest pass test was used to measure arm power, leg power utilizing the vertical jump test, and speed world record performance using the IFSC's automatic timing system with a standard resolution of 1/1000 of a second for the 15-meter course completion time. Using SPSS version 25, statistical analysis includes descriptive tests, the Shapiro-Wilk normality test, and Spearman's rho correlation test. Upper-body power was strongly and negatively associated with climbing time ($r_s = -.802$, $p = .017$, approximate 95% CI [-.935, -.473]), and lower-body power showed a similar strong negative association ($r_s = -.814$, $p = .014$, approximate 95% CI [-.939, -.497]). Upper- and lower-body power were also strongly positively associated ($r_s = .820$, $p < .05$). These findings indicate that athletes with higher upper- and lower-body power tended to record faster climbing times. Because the study used a correlational design and a small sample, the results should be interpreted as associations rather than evidence of causality.

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Introduction

Over the past ten years, speed climbing has experienced a dramatic transformation in performance. With Samuel Watson (USA) setting the most recent record of 4.64 seconds at the 2025 Bali World Cup, the men's world record, which was 6.26 seconds in 2011, has now dropped below 5 seconds, while Aleksandra Mirosław (Poland) holds the women's record at 6.06 seconds (IFSC, 2024). This rate of record decline, more than 25%

over 14 years, is a result of athletes' biomotor capacity being systematically optimized, especially their capacity to produce explosive power in less than 5 seconds, rather than just technological advancements (Hosseini & Wolf, 2023). Since the 2018 Asian Games, speed climbing has been a national priority in Indonesia. This performance leap has coincided with speed climbing's elevation to full Olympic status, which has intensified both scientific attention and competitive standardization of the discipline worldwide (Lutter et al., 2020). Nevertheless, there is still a large gap between nationally trained athletes and world record standards, which suggests that physical conditioning programs need to take a more scientifically based approach (FPTI, 2022).

From a physiological and biomechanical standpoint, the ATP-PC (phosphocreatine) energy system, which facilitates extremely brief alactic anaerobic work, dominates speed climbing performance (Guo et al., 2019; Sahlin, 2014). 92% of elite athletes employed the "Tomoa start" strategy, which explicitly maximizes lower-body power to minimize lateral displacement of the body's center of mass, according to video analysis of the 2020 Tokyo Olympics final (Hosseini & Wolf, 2023). The top 10 male competitors in the World Cup had an average leg power of 25-26 W/kg and an average vertical speed of 2.5 m/s (Ozimek et al., 2018). Beyond leg-power output alone, broader physical and physiological determinants—including shoulder power, energy-system efficiency, and neuromuscular capacity—have been shown to jointly separate elite from sub-elite climbers, underscoring the multifactorial nature of climbing performance (MacKenzie et al., 2020). Climbing-specific exercise testing further indicates that anaerobic alactic and lactic energy pathways make disproportionately large contributions during short, high-intensity efforts such as speed ascents, reinforcing the physiological rationale for prioritizing explosive power development in training (Maciejczyk et al., 2022).

However, there is a substantial discrepancy between the field's training procedures and the actual evidence that is now accessible. Without measuring the precise contributions of each power component to performance, the majority of speed climbing training programs in Indonesia are still created using a generic method (Ozimek et al., 2018). Previous research has either concentrated on the general physiology of rock climbing without examining the relationship between upper and lower body power independently, using useful field test instruments (Levernier & Laffaye, 2019; Saul et al., 2019) or on international elite athletes (Hosseini & Wolf, 2023; Levernier & Laffaye, 2019). There is hardly any research in the literature that precisely examines these two elements in national-level speed climbing athletes utilizing the chest pass and vertical jump tests with Spearman's rho analysis, especially in the Indonesian setting. Coaches are left without a scientific foundation to decide which training priorities will increase climbing times as a result of this lack of data.

The basic necessity for local empirical data that can be immediately converted into evidence-based training recommendations is what makes this study vital. This study is novel in three ways: (1) it analyzes the relationship between two dominant power components using standardized field tests in the context of national-level athletes; (2) it compares the strength of the relationship between climbing time and upper-body versus lower-body power, which has never been published for the population of FPTI Kota Bandung athletes; and (3) it offers quantifiable training recommendations that coaches can directly implement within annual periodization.

Method

Research Design

This study uses a correlational design and a quantitative methodology. Since measuring and quantifying the correlations between variables numerically and testing them statistically is the main goal of the study, the quantitative technique was selected (Creswell & Creswell, 2022). Because this study analyzes variables under the athletes' natural conditions rather than administering treatments (experiments) in order to find and describe the interactions that occur between variables, a correlational method was employed (Thomas et al., 2015). This method is consistent with a number of earlier sports science studies that examined the connection between physical condition elements and athletic performance using comparable designs (Levernier & Laffaye, 2019; Saul et al., 2019).

Research Participants

During the data collection period (April 2026), eight speed climbing athletes (n=14; 7 male, 7 female) who were registered and actively engaged in the Indonesian Climbing Federation's (FPTI) training program in Bandung served as the research subjects. Subject features include an average age of 14-17 years, a minimum of three years of training experience, and active participation in regional and national competitions. All individuals of the population who met the requirements were included in the sample using the total sampling technique (Sugiyono, 2015). The requirements were as follows: (1) being registered as a current FPTI Bandung City athlete; (2) having competed at the regional or national level; and (3) not having an active injury at the time of data collection. The main drawback of the small sample size (n=14) is widely recognized: generalizations only apply to similar groups, statistical power is constrained, and research findings must be evaluated cautiously (Field, 2018).

Research Instruments
In this investigation, three instruments were employed. First, upper body muscle power is measured with the Medicine Ball Chest Pass Test. Sport climbing research frequently uses this instrument, which has a validity of r = 0.84 and a reliability of r = .97 (Harman et al., 1991; Putra et al., 2024; Winkler et al., 2023). Athletes hold a medicine ball (3 kg for males and 2 kg for women) in front of their chest while sitting with their backs against a wall. They then forcefully push the ball forward without raising their buttocks. Meters (m) are used to record the farthest throw distance from three trials, separated by a one-minute pause. The Vertical Jump Test, which gauges lower-body muscle strength, comes in second. This test is frequently used for elite speed climbers (Levernier & Laffaye, 2019; Ozimek et al., 2018) and has been verified in a variety of sporting situations with an ICC of .97 (Sattler et al., 2020). The selection of standardized, climbing-relevant field tests in this study is further supported by the International Rock Climbing Research Association's sport-specific test battery, which recommends practical power-based assessments for use across climbing disciplines and competitive levels (Draper et al., 2021). This approach is also consistent with a recent systematic review indicating that, among the wide range of performance tests used in climbing research, those assessing explosive power tend to show comparatively stronger reliability and validity evidence than several other physical fitness measures (Langer et al., 2023). The athlete jumps as high as they can after standing upright next to the wall and reaching as high as they can with one hand (a technique known as standing reach). The vertical jump score, measured in centimeters (cm) from the best of three tries, is the difference between the standing reach height and the jump reach height. Third, the automated timing system of the IFSC, with a precision of 1/1000 of a second, is used in the 15-Meter Speed Climbing Performance Test. Because it employs an internationally standardized system with electronic sensor-based measurements, reducing human error, this instrument has extremely high validity and reliability (IFSC, 2023). The athlete starts with at least one foot on the starting pad and climbs a 15-meter-high IFSC standard route with a 5° overhang until they press the timing sensor at the summit. After three attempts with rest intervals of five to ten minutes, the best time is recorded in seconds.

Procedure for Gathering Data
To reduce the impact of variables or other confounding factors, data collection was conducted in a single, standardized, laboratory-based session. Strength and power tests (vertical jump test and chest medicine ball throw test) were conducted at the Sports Science Laboratory, Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, and rock climbing performance tests were conducted at the FPTI Bandung Training Wall. The order of the tests was as follows: (1) 20-minute static and dynamic warm-up; (2) vertical jump test (low neuromuscular load, low risk of fatigue); (3) chest medicine ball throw test; (4) 30-minute active rest; (5) rock climbing performance test; and (6) 10-minute cool-down.

Data Analysis
SPSS version 25 was used to analyze the data in phases. Descriptive analysis (mean, standard deviation, minimum-maximum values) was used in the first stage to characterize each variable's properties. The Shapiro-Wilk normality test was used in the second step (chosen because n < 30; Field (Field, 2018)) with the condition that data are normally distributed if p > .05. Correlation analysis was conducted using a non-parametric approach because the results of the normality test showed that not all variables satisfied the normality assumption. In order to ascertain the association between arm power and leg power and the performance of speed world record-category rock climbers, the third stage employed Spearman's rho correlation test. The Spearman test was selected because it is better suited for small sample sizes and does not require a normal data distribution (Creswell & Creswell, 2022; Field, 2018). A more contextual, modern empirical method is used in this work to interpret correlation strength, which is categorized as follows: r = < .10 very weak; .10-.20 weak; .20-.30 moderate; and > .30 high. This method makes more realistic conclusions based on the context of the subject of study because impact sizes in contemporary research are typically smaller. A significance level of α=.05 was used.

Results and Discussions

Descriptive Statistics
An overview of the variables for medicine ball, vertical leap, and speed word record performance is shown in Table 1. Table 1 shows that the athletes' average arm power score was 3.51 m (SD = .66), with a minimum score of 2.60 m and a maximum score of 4.60 m. With a significant degree of data dispersion (coefficient of variation = 18.7%), this range of results shows diversity in arm power capability among athletes. This implies that arm power capacity varies somewhat among athletes but stays within a moderate range. With a minimum of .40 m and a maximum of .59 m, the average leg power score was .46 m (SD = .07).

Table 1 <Research Variable Descriptive Statistics>

Variable	N	Min.	Max.	Mean	SD
Arm Power	14	2.60	4.60	3.5125	0.65778
Leg Power	14	.4	0.59	0.4613	0.07019
Performance	14	5.76	19.24	11.9675	4.59595

The athletes' leg explosive power was comparatively more homogeneous, as seen by the decreased variation in leg power (coefficient of variation = 15.2%) compared to arm power. The fastest time for performance was 5.76 seconds, while the slowest time was 19.24 seconds. The average speed ascending time was 11.97 seconds (SD = 4.60). The competitors' performance varies significantly, as evidenced by the very large time range (13.48 seconds). The athletes' ability to finish the speed course is still very diverse, as seen by the significant variability (coefficient of variance = 38.4%). Notably, the average completion time of 11.97 seconds is still higher than the world-class top athletes' performance standard (±4-6 seconds), indicating that the study participants are still in the developmental stage. This significant performance variance offers suitable circumstances for examining the connection between power components and performance in this investigation.

Results of the Normality Test

The Shapiro-Wilk test was performed to evaluate the data's normality before choosing the correlation test. This test was used since the study's sample size was extremely small (n = 14), making the Shapiro-Wilk test more relevant and sensitive than the Kolmogorov-Smirnov test, which is better suited for larger samples (Field, 2018). Table 2 displays the shapiro-wilk normality test results.

Table 2 <Shapiro-Wilk Normality Test Results>

Variable	Statistic	Sig.	Information
Arm Power	.941	.625	Normal
Leg Power	.801	.030	Non-Normal
Performance	.974	.911	Normal

According to Table 2, the Shapiro–Wilk normality test results show that the arm power variable is normally distributed, with a statistic value of .941 and a significance value of .625 ($p > .05$). The performance variable is also normally distributed, with a statistic value of .974 and a significance value of .911 ($p > .05$). In contrast, the leg power variable is not normally distributed, with a statistic value of .801 and a significance value of .030 ($p < .05$). These results indicate that not all variables meet the normality assumption. Therefore, Spearman's rho correlation test, as a non-parametric statistical method, was used to analyze the relationship between arm power, leg power, and speed climbing performance.

Results of the Spearman's Rho Correlation Test

The Spearman's rho correlation test was used to ascertain the association between the two independent variables and the relationship between arm power, leg power and performance of speed world record category rock climbing athletes. Table 3 displays all of the test findings.

Table 3 <Results of Spearman's Rho Correlation Test>

Variable	Correlation Coefficient (r)	Sig.	Information	Strength of Relationship
Arm Power – Performance	-.802	.017	H_0 rejected	Very Strong
Leg Power – Performance	-.814	.014	H_0 rejected	Very Strong

Based on Table 3, the correlation analysis demonstrates that all variables have statistically significant relationships, as indicated by the significance values below.05, resulting in the rejection of the null hypothesis (H_0 rejected). The arm power and performance exhibit a very strong negative correlation ($r = -.802$, $p = .017$), and leg power and performance also reveal a very strong negative correlation ($r = -.814$, $p = .014$). These negative correlations suggest that higher levels of arm and leg power are associated with lower performance scores, which may indicate better performance outcomes when lower scores represent superior achievement, such as faster completion times. Overall, the findings indicate that arm and leg power are important physical components that significantly contribute to the performance of of speed world record category rock climbing athletes.

The Relationship between Arm Power with Arm Power of Speed World Record Category Rock Climbing Athletes

According to the study's findings, one of the most important indicators of athlete performance in the speed world record category is arm power. The role of the upper extremity muscles, specifically the latissimus dorsi, biceps brachii, triceps brachii, and forearm flexor muscles, in producing propulsive power during each pulling movement on the climbing wall, provides a biomechanical explanation for this link. The ability of the arm muscles to produce maximal force in a very short amount of time is crucial for the effectiveness of force transmission from the hand to the hold during speed climbing (Laffaye et al., 2016). In competitive speed climbing, athletes are required to execute repetitive explosive pulling actions while maintaining body stability throughout the ascent. This condition places a substantial demand on upper-body muscular endurance and rapid force production. Athletes with superior arm power are generally able to maintain climbing rhythm more efficiently, particularly during the acceleration phase after the start. In addition, stronger upper extremity muscles may help reduce unnecessary body sway, allowing climbers to conserve momentum and move more directly toward the next hold. As a result, the efficiency of upper-body force application becomes a decisive factor in achieving optimal climbing times.

The predominant type II muscle fiber composition in speed athletes, which has greater contraction rates and force generation than type I fibers, physiologically determines this capacity (Schoffl et al., 2019). The only performance indicator in the speed discipline, total travel time, can be decreased by athletes with strong upper bodies since they can accelerate their bodies vertically more quickly. Furthermore, athletes with higher proportions of fast-twitch muscle fibers tend to demonstrate superior explosive movement characteristics during dynamic climbing actions. These physiological advantages become particularly important during the initial and transitional phases of climbing, where milliseconds can determine competition outcomes. The repeated requirement for rapid contractions also highlights the importance of anaerobic energy system efficiency in speed climbing performance. Therefore, training programs for speed climbers should not only emphasize maximal strength development but also focus on explosive power and neuromuscular reactivity. Such adaptations may improve the athlete's ability to generate force rapidly under highly competitive conditions.

These results support the claim made by Baláš et al. (Baláš et al., 2020) that on the IFSC standardized course, upper extremity neuromuscular capacity considerably separates elite athletes from sub-elite athletes. However, it must be recognized that arm strength does not function alone; the degree to which arm power may be transformed into the best climbing speed is also moderated by coordination between body segments and the effectiveness of movement technique (Vieira et al., 2021). The relationship between arm power and speed is not strictly linear; rather, it is mediated by technical and tactical factors, such as route selection (beta), hand-step frequency, and breathing rhythm, which also influence actual performance on the course (Baláš et al., 2020). Beyond these technical mediators, neuromuscular capacity is itself a key determinant separating high-performing from lower-performing climbers, and its expression can fluctuate as fatigue accumulates across repeated maximal efforts, meaning that both peak power and fatigue resistance jointly determine how effectively arm strength translates into climbing speed (MacKenzie et al., 2020). In practice, elite climbers often demonstrate smoother movement patterns and more precise timing during transitions between holds. Efficient coordination between the upper and lower body enables athletes to minimize wasted movement and maintain momentum throughout the climb. Tactical decision-making, including optimal hold utilization and pacing strategy, may also influence the effectiveness of power application during competition. Additionally, psychological aspects such as concentration, reaction time, and competitive composure can contribute to successful execution under high-pressure conditions. Therefore, speed climbing performance should be understood as a multidimensional construct involving physiological, biomechanical, technical, and psychological components simultaneously.

Another important aspect that may explain the relationship between arm power and speed climbing performance is movement economy during repeated explosive actions on the standardized route. Athletes who possess higher arm power are generally capable of generating greater force with less relative muscular effort, allowing them to maintain climbing efficiency from the start phase until the final hold. This efficiency becomes highly beneficial during high-intensity performances where even slight decreases in movement speed can significantly affect overall climbing time. In addition, stronger arm power may help athletes recover more rapidly between successive pulling movements, reducing muscular fatigue accumulation throughout the ascent. From a practical perspective, these findings suggest that strength and conditioning programs for speed climbers should integrate explosive upper-body exercises with climbing-specific movement drills to improve both force production and technical execution simultaneously. Consequently, the development of arm power should not only be viewed as a physical attribute but also as an essential component that supports the consistency and efficiency of competitive speed climbing performance.

The Relationship between Leg Power with Arm Power of Speed World Record Category Rock Climbing Athletes

This study shows that lower-body power has a substantial role in fast climbing performance in addition to upper-body strength. These results support the idea that the lower extremities play an important role in fast climbing. In terms of biomechanics, the legs serve as the main source of propulsion when an athlete pushes their body upward during the push-off phase, which lessens the strain on their arms (Draper et al., 2016). Athletes can sustain momentum without solely depending on arm strength by activating major muscles like the quadriceps femoris, gastrocnemius, and gluteus maximus, which produce significant vertical explosive power (Stien et al., 2021). Findings from systematic reviews of countermovement jump performance also indicate that, beyond peak lower-body power, movement biomechanics during the braking and propulsive phases of a jump substantially influence explosive output, suggesting that speed climbing training should target both the magnitude and the timing of force application in the legs (Bygate-Smith et al., 2025). In speed climbing, rapid and coordinated leg drive enables athletes to move efficiently between footholds while maintaining body balance throughout the ascent. Strong lower-body muscles also contribute to faster transition movements, particularly during dynamic phases where athletes must instantly reposition their feet. This ability allows climbers to preserve movement rhythm and minimize unnecessary pauses during climbing. In addition, effective force production from the lower limbs can reduce upper-body fatigue accumulation, especially during repeated high-intensity attempts in training and competition. Therefore, lower-body power should be considered an essential physical component in achieving optimal speed climbing performance.

From the standpoint of sports physiology, speed climbing relies heavily on the alactacid anaerobic energy system because it is a very brief activity (±5-7 seconds at the elite level). In these circumstances, creatine phosphate storage capacity and active muscle mass, especially in the lower limbs, affect the phosphagen system's efficiency as the main energy source (Bertuzzi et al., 2012). With each step on a footing, athletes with more lower-body power typically produce more ground response force, which increases the vertical displacement speed throughout each movement cycle. Because of the extremely short duration of competition, athletes are required to generate maximal power output almost immediately after the starting signal. This places substantial physiological demands on neuromuscular activation and explosive muscle recruitment in the lower extremities. Athletes with better phosphagen system efficiency are generally able to maintain high-intensity movements without experiencing significant decreases in power production during the climb. Furthermore, rapid force generation from the lower limbs contributes to smoother acceleration patterns during the early climbing phase, which is often decisive in elite-level competition. These physiological adaptations highlight the importance of explosive power training and anaerobic conditioning in speed climbing preparation programs.

The power-to-weight ratio should also be taken into account because performance is based on both absolute power and force generation capacity in relation to body mass. Lower-body power cannot be examined in isolation from body weight and body fat percentage because athletes with appropriate body composition benefit from increased acceleration (Stien et al., 2021). Athletes with excessive body mass may experience greater mechanical resistance during vertical movement, which can negatively affect climbing efficiency despite having high muscular strength. Conversely, climbers with optimal body composition are generally able to convert muscular force into movement more effectively while reducing unnecessary energy expenditure. This condition becomes increasingly important in speed climbing, where performance outcomes are determined within only a few seconds. In addition, maintaining an appropriate balance between muscular development and body mass may help athletes improve movement control and coordination during rapid climbing actions. Therefore, physical conditioning programs for speed climbers should integrate lower-body power development with body composition management to maximize overall climbing performance.

The strengthen of the relationship between lower-body power and speed climbing performance is the athlete’s ability to generate rapid force repeatedly while maintaining movement precision on the standardized route. In competitive speed climbing, efficient leg propulsion allows athletes to initiate upward movement more aggressively and maintain acceleration throughout consecutive climbing phases. Athletes with greater leg power are also more capable of absorbing and redirecting force quickly during foot placement transitions, which contributes to smoother and more controlled movement patterns. This mechanical efficiency may reduce unnecessary muscular tension in the upper body, enabling climbers to preserve energy and sustain optimal climbing rhythm until the finish. From a training perspective, these findings suggest that plyometric exercises, explosive jump training, and climbing-specific lower-limb drills should be integrated systematically into conditioning programs to improve both force production and movement efficiency in elite speed climbers.

Practical Implications for Training

Lower-body plyometric activities, including depth jumps, box jumps, and squat jumps, should be given priority in speed climbing training programs during the power development phase due to the considerable contribution of lower-body power (82.8%) (Bompa & Buzzichelli, 2019; Ehiogu et al., 2023). However, considering its significant contribution (75.7%), upper-body power should not be disregarded. The training cycle must include exercises like medicine ball throws, weighted pull-ups, campus board training, and plyometric push-ups (Palmer, 2020). This recommendation is reinforced by controlled training evidence showing that a structured medicine ball training program can produce meaningful gains in upper-body muscular strength and power among athletes within a relatively short training cycle, supporting its practical value as a low-cost, climbing-relevant training tool (Ignjatović et al., 2012). Circuit training that incorporates both components in a single session can offer the biggest benefit in terms of training time optimization due to the strong link between the two and their synergistic effects on simultaneous contributions. Coaches will be able to objectively track power growth with the aid of a periodization program that specifically identifies vertical leap and chest pass as measures of physical condition advancement (Harsono, 2017).

Conclusions

The results of this study indicate that both upper-body power and lower-body power have strong negative correlations with speed climbing time, meaning that athletes with higher power levels tend to record shorter climbing times. In addition, upper-body power and lower-body power were positively correlated, suggesting that these two physical components may be related in speed climbing athletes. However, these findings should be interpreted with caution because this study used a correlational design, involved a small sample size, did not apply random sampling, and did not conduct sex-specific analysis. Therefore, the results cannot be used to establish a direct cause-and-effect relationship. Other factors such as climbing technique, reaction time, body composition, training history, and psychological readiness were also not examined in this study. From a practical perspective, coaches are encouraged to consider both upper-body and lower-body explosive power training in speed climbing programs, supported by regular monitoring through the medicine ball chest pass test, vertical jump test, and climbing time assessment.

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