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Role of Strategic Planning in Climbing Performance: The Case of Olympic Bouldering

Jerry Prosper Medernach[1, 2], Julian Henz[1], Daniel Memmert[1], and Xavier Sanchez[3, 4, 5]

[1] Institute of Exercise Training and Sport Informatics, German Sport University Cologne
[2] Institut National de l'Activité Physique et des Sports, Ministry of Sport, Luxembourg City, Luxembourg
[3] Complexité, Innovation and Activités Motrices et Sportives, Sciences et Techniques des Activités Physiques et Sportives, Université d'Orléans
[4] Complexité, Innovation and Activités Motrices et Sportives, Université Paris-Saclay
[5] Sport, Activité Physique, Rééducation et Motricité pour la Performance et la Santé, Université d'Orléans

Bouldering is an Olympic discipline that encompasses a series of short climbing sequences on low-height structures called boulders. Strategic planning is paramount in competitive bouldering to both identify suitable climbing strategies before climbing and adapt climbing strategies after failed attempts. The ability to identify suitable climbing strategies depends upon an extensive climbing movement repertoire, conceptualized as high-level knowledge structures stored in long-term memory. This study aimed at examining strategic planning in the context of a bouldering competition to gain further insight into mechanisms underlying strategy proficiency in Olympic bouldering. Thirty male competitors in the semifinals at a national bouldering championship voluntarily participated in the study. A series of climbing-related performance and strategic planning parameters were examined, including suitability of competitors' climbing strategies, adjustments they made to their initial strategies, and their climbing movement repertoire. Linear regressions revealed significant relations between climbers' bouldering performance (number of completed boulders and failed climbing attempts) and their climbing strategy suitability, their strategy adjustments following their first attempts at the boulders, and their climbing movement repertoire. Findings underpin previous research revealing that mastering competitive bouldering is associated with climbers' ability to develop appropriate climbing strategies relative to the climbing movements of boulders. Findings furthermore reinforce the movement repertoire paradigm, as climbers who exhibited better bouldering performances were characterized by a superior climbing movement repertoire, enabling them to quickly interpret visual sensory input and identify meaningful climbing movement patterns during boulder previewing.

Keywords: decision making, expertise, movement repertoire, route preview, strategy

Jerry Prosper Medernach https://orcid.org/0000-0003-1873-2704
Julian Henz https://orcid.org/0000-0001-7966-0092
Daniel Memmert https://orcid.org/0000-0002-3406-9175
Xavier Sanchez https://orcid.org/0000-0002-3498-0276
Xavier Sanchez is now at the Department of Sport Sciences, Université d'Orléans.

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Correspondence concerning this article should be addressed to Xavier Sanchez, Department of Sport Sciences, Université d'Orléans, 2 Allée du château, 45062 Orléans, France. Email: xavier.sanchez@univ-orleans.fr

Olympic climbing comprises three disciplines: speed climbing, sport climbing, and bouldering (Hatch & Leonardon, 2023). In the discipline of speed, climbers must ascend a standardized route as fast as possible. In sport climbing, athletes have a single attempt, called "onsight," to climb a route of at least 15 m in height. Bouldering encompasses a series of short climbing sequences on low-height structures called boulders, which athletes climb without the use of ropes and harnesses. The present study focuses on bouldering competitions, where climbers face the unique challenge of solving a series of boulders featuring technically and physically demanding climbing movements within a given time frame and limited time to rest between boulders (Hatch & Leonardon, 2023). Given that in competitive bouldering, performance results are based upon the number of successfully completed boulders and the number of climbing attempts required to complete these boulders, strategic planning is a critical parameter to achieve best competition outputs (Medernach & Memmert, 2021; Whitaker et al., 2020).

In the sporting context, strategy refers to the deliberate planning and guidance of motor actions prior to their execution (Hibbs & O'Donoghue, 2013; Low et al., 2020). Exploring strategic opportunities draws on existing knowledge of the sport-specific context (e.g., weaknesses of opponents), recent occurrences (e.g., environmental factors), and current states of athletes (Buekers et al., 2020; Lord et al., 2020). In competitive bouldering, strategic planning encompasses three scenarios: (a) identifying appropriate climbing strategies prior to attempting boulders, (b) adapting climbing strategies after failed climbing attempts, and (c) effective time management (Medernach, Sanchez, et al., 2024).

Recent research has shown that climbers' strategic planning depends on the climbing movement characteristics of boulders. Climbing movement characteristics encompass the specific movements of boulders, requiring particular techniques to climb them effectively and efficiently (Henz et al., 2024). Augste et al. (2021) and Mckellar et al. (2023) analyzed the strategic planning of world-class bouldering competitors during a series of International Federation of Sport Climbing (IFSC) World Cups. Their findings revealed, for instance, that competitors made fewer attempts at physically exhausting boulders with high physical demands than at technically demanding boulders with precise and controlled climbing movements. Additionally, Mckellar et al. (2023) found that, irrespective of the type of boulder, the threshold to successfully completing boulders was six attempts, with zero success rate beyond that. In this context, Künzell et al. (2021) observed at several bouldering World Cups that, following failed climbing attempts, developing new climbing strategies contributed more often to successful boulder completion than repeating the same strategy from previous attempts.

So far, strategic planning prior to attempting boulders and after failed climbing attempts has hardly been investigated. In Kahneman's (2012) dual-process model of cognition, athletes' decision making arises from either deliberate and analytical problem-solving processes (slow thinking) or automatic and intuitive processing (fast thinking). Referring to this model, competitive bouldering encompasses predominantly deliberate and analytical problem-solving processes, particularly before attempting boulders and after failed climbing attempts, while intuitive decisions may occur only marginally, such as during final attempts shortly before climbing time expires.

In competitive bouldering, climbers operate in relatively stable and predictable environments, with sufficient time to prepare subsequent motor actions. Yet, a major constraint to developing appropriate climbing strategies is the vast array of climbing holds and infinite climbing movement constellations, contributing to movement variability and requiring climbers to constantly adapt their problem-solving strategies and motor actions, despite time constraints (Medernach & Memmert, 2021; Neumann, 2019). Drawing on Poulton's (1957) concept of environmental predictability, competitive bouldering can thus be considered a relatively open-skill sport, despite relatively stable and predictable environments and a limited number of climbing techniques (Medernach & Memmert, 2021).

To develop appropriate climbing strategies, climbers visually inspect boulders before ascending them. During this so-called boulder previewing, climbers process visual sensory inputs, gather functional information through visual cues of climbing holds, and mentally rehearse climbing movements (Medernach, Sanchez, et al., 2024). These skills are crucial for identifying potential strategies to solving boulders and thus for strategic planning prior to attempting them (Medernach & Memmert, 2021). Boulder previewing is of particular relevance in competitive bouldering, as climbers are not allowed to physically rehearse boulders in advance (Hatch & Leonardon, 2023).

The appropriate processing of visual sensory input draws on an extensive repertoire of climbing movements, conceptualized as high-level knowledge structures stored in long-term memory. Specifically, experts' profound repertoire of climbing movements enables them to quickly understand and anticipate the characteristics of climbing movements processed in short-term memory (Medernach, Henz, & Memmert, 2024). This implies that, in addition to boulder previewing, strategic planning of climbing ascents also draws upon the movement repertoire paradigm, which posits that climbers use their repertoire to identify familiar climbing movement patterns based on the arrangement of climbing holds and to cluster visual perceptual stimuli into a climbing choreography comprising a series of climbing movements (Medernach, Henz, & Memmert, 2024).

The movement repertoire paradigm is inherently associated with the conceptual framework of the matching theory, originating from Herrnstein's (1970) seminal work on how behavioral responses are influenced by reinforcement. The pattern-matching theory postulates that, when several functionally equivalent responses are available, humans interpret sensory input by using previously stored patterns in long-term memory (du Castel, 2015). Research underpinning the pattern-matching paradigm draws on the seminal works on cognitive processes underlying expert performance in chess by De Groot (1956) and Chase and Simon (1973); their works uncovered that expert chess players were able to quickly encode and retrieve meaningful patterns, such as familiar configurations of pieces or common opening movements, allowing them to efficiently process relevant information and plan strategies. Beyond chess literature, research on music reading, for instance, supports the pattern-matching paradigm, showing that experienced musicians' sight-reading (e.g., shorter fixations, larger saccade amplitudes) is associated with their ability to rapidly perceive groups of notes (Sheridan & Kleinsmith, 2022). In a recent study on memory in bouldering, it has been proposed that recognizing familiar climbing movement patterns helps climbers in memorizing climbing movements by clustering perceptual stimuli into motor chunks comprising a series of climbing holds associated with motor action (Medernach, Henz, & Memmert, 2024).

In contrast to the ability of identifying appropriate climbing strategies and adapting climbing strategies after failed climbing attempts, time management in competitive bouldering has received considerable attention. Effective time management is of particular relevance during IFSC qualifications and semi-finals, in which climbers attempt four to five boulders in a predefined sequence, with a climbing time per boulder and a rest time in-between boulders of 5 min (Hatch & Leonardon, 2023). That is, time constraints limit the number of attempts per boulder (Augste et al., 2021; Medernach et al., 2016). To date, research has used video recordings to investigate the time management strategies of elite and world-class competitors. These studies have shown that climbers typically make three to five climbing attempts per boulder, with each attempt lasting on average 20–40 s and rest times in-between boulders lasting approximately 30 s (Mckellar et al., 2023; Medernach et al., 2016; White & Olsen, 2010).

Today, empirical studies on strategic planning in bouldering are still sparse and have primarily been confined to either ex situ analyses of video recordings without in-depth assessment of performance determinants or outside of competitive contexts and thus lacking ecological validity—research, particularly, has yet to explore the extent to which strategic planning determines bouldering performance of competitors. Therefore, the purpose of the present study was to examine strategic planning in competitive bouldering to gain further insight into potential mechanisms underlying strategy proficiency among successful climbers. To that end, we examined a series of climbing-related performance and strategic planning parameters during a national bouldering competition, including the suitability of competitors' climbing strategies, adjustments they made to their initial strategies, and their climbing movement repertoire.

Building on previous research in bouldering (Medernach, Sanchez, et al., 2024; Whitaker et al., 2020), we hypothesized that (Hypothesis 1) climbers exhibiting better competitive performances (completing more boulders in fewer attempts) would be characterized by superior strategic planning skills, thereby requiring less time to develop their climbing strategies, developing more suitable climbing strategies, and requiring fewer adjustments to their strategies following initial climbing attempts than less successful climbers. Furthermore, drawing on the movement repertoire paradigm (Medernach, Henz, & Memmert, 2024) and the inherently related conceptual framework of the matching theory (Herrnstein, 1970), we hypothesized that (Hypothesis 2) climbing performance would be associated with an extensive climbing movement repertoire, allowing more successful climbers to better identify meaningful climbing movement patterns and to make better perceptual judgments of their climbing capabilities during boulder previewing (Medernach & Memmert, 2021; Whitaker et al., 2020).

Method

Participants

Thirty male (i.e., this biological sex assignment adheres to IFSC rules) climbers (30.4 ± 9 years, 7.5 ± 2 years climbing experience, 20.8 ± 1 International Rock Climbing Research Association [IRCRA] points, advanced bouldering level) voluntarily participated in the study. Participants consisted of all 30 competitors in the semifinals at a national bouldering championship; semifinals included the top 30 athletes from the preceding qualifying round, as stipulated by the competition rules. The competitive setting of this field study enabled the investigation into the strategic planning of highly experienced climbers. However, an a priori power analysis was not feasible, as the structure of the competition determined the sample size (n = 30). Furthermore, the study did not include female climbers due to the considerably lower number of female competitors who were assigned separate boulders from male athletes. All participants provided written informed consent and were informed verbally and in writing about the purpose and procedures of the study. Participants were required to be at least 18 years old, in good health, and without any recent injuries that could have impacted their climbing performance. The study was conducted in conformity with the World Medical Association and received ethical approval from the University Ethics Committee (Number 057/2021).

Based on their ranking in the preceding qualification round, participants were allocated to one of three study groups: the TOP group (n = 10), including the top 10 ranked climbers; the MID group (n = 10), including the 11–20 ranked climbers; and the BOT group (n = 10), including the bottom 10 ranked climbers (see Table 1). This facilitated group comparisons based on competition scores by ensuring an equal distribution of participants across each study group.

Procedure

Upon arriving at the bouldering venue, participants completed the consent form and filled out a questionnaire to assess their sport-specific background. In line with IFSC rules, they had to remain

Table 1
Personal Characteristics and Sport-Specific Background of the Study Groups

	TOP group		MID group		BOT group		Between group		
Variable (unit)	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*/*H*	*p*	*r*
Age (years)	30.5	10_{MIDa}	29.3	8_{BOTa}	31.5	9_{TOPa}	$F = 0.15$	.863	.11
Weight (kg)	65.8	6_{MIDb}	69.9	9_{BOTb}	66.0	13_{TOPa}	$F = 0.60$	.558	.20
Height (cm)	177.9	4_{MIDa}	178.8	7_{BOTb}	175.8	11_{TOPa}	$F = 0.41$	.668	.17
Grip strength (N)	373	60_{MIDa}	360	86_{BOTa}	369	114_{TOPa}	$F = 0.06$	.939	.07
IRCRA (score)[a]	21.0	1_{MIDb}	21.0	1_{BOTb}	20.4	1_{TOPb}	$H = 1.66$	.436	.23
Climbing (years)	7.3	3_{MIDb}	8.0	3_{BOTa}	7.1	3_{TOPb}	$H = 0.34$	.844	.13
Competitions (number)	18.4	$9_{\text{MIDd}}^{\dagger}$	9.2	5_{BOTa}	9.3	$6_{\text{TOPd}}^{\dagger}$	$H = 8.92$	.012	.56
Technical skills (score)[b]	3.6	0.5_{MIDb}	3.4	0.5_{BOTb}	3.2	0.6_{TOPc}	$H = 2.28$	.319	.29

Note. Results are reported as mean ± standard deviation, followed by statistical comparisons between two groups using subscript characters, including the group being compared to ($_{\text{TOP}}$, $_{\text{MID}}$, $_{\text{BOT}}$) and letters denoting the effect size r ($_a r < .1$, $_b 1 \leq r < .3$, $_c 3 \leq r < .5$, $_d r \geq .5$). Between-group comparisons include either the analysis of variance (F) or Kruskal–Wallis (H) result, the p value, and the effect size r. TOP = top 10 ranked climbers; MID = 11–20 ranked climbers; BOT = bottom ten ranked climbers; IRCRA = International Rock Climbing Research Association.
[a] International Rock Climbing Research Association's numerical scale of for classifying climbing skills. [b] Self-assessment using a 5-point Likert scale (i.e., 1 = *poor*, 2 = *fair*, 3 = *good*, 4 = *very good*, 5 = *excellent*).
† $p < .05$.

in a separate isolation zone before the start of the semifinals to prevent any premature exposure to the boulders. In the isolation zone, they completed their routine warm-up program to enable individual physiological and psychological preparation. Once participants indicated that they were sufficiently warmed up and mentally ready, their body characteristics and grip strength, as well as their preperformance mental and physical states, were assessed.

Following these initial test procedures, participants were successively exposed to the four boulders of the semifinals. Complying with IFSC procedures, they were required to attempt the boulders in a predefined sequence and series of rotations. Additionally, again in conformity with IFSC rules, participants had no separate observation periods for the boulders; boulder previewing was within the time limitation of the given 5 min. The constellation of the boulders and rotation procedure prevented participants from observing other climbers' performances. Following each boulder, participants' perceived exertion was assessed, and blood lactate samples were taken, similar to Draper et al. (2006) and La Torre et al. (2009), after a 2-min recovery period.

Measures

Personal Characteristics and Sport-Specific Background

Given that anthropometric characteristics can impact climbing performance (Mitchell et al., 2011), body weight was measured in shorts and T-shirts to the nearest 0.1 kg by using a Seca 760 scale. Body height was determined without shoes to the nearest 0.5 cm by using a Seca 213 stadiometer. In addition, grip strength, a key performance factor in competitive bouldering (Medernach et al., 2015), was measured using a calibrated Smedley Spring dynamometer. Participants were instructed to perform three repetitions with their dominant hand (without thumb) by gradually applying maximal pressure for 2 s. The highest score was recorded with a 1-min standardized rest period between two consecutive trials (see Medernach et al., 2015).

Participants' climbing ability levels and their technical climbing skills (see Table 1) were self-assessed. Specifically, their climbing ability level was determined using the IRCRA scale and encompassed the most difficult boulder participants managed to climb "onsight" (i.e., on their first attempt) at the time of the study (i.e., *what is your current onsight bouldering level?*). The IRCRA scale incorporates common grading scales and allows them to be converted into a numbering system. It is considered reliable and valid for classifying climbing ability, thereby assigning climbers to specific ability groups (see Draper et al., 2015). Technical skills (i.e., *rate your overall level of technical climbing proficiency on the following scale*) were assessed using a 5-point Likert scale (i.e., 1 = *poor*, 2 = *fair*, 3 = *good*, 4 = *very good*, 5 = *excellent*).

Preperformance Mental and Physical States

As psychological states preceding climbing competitions have been described as a crucial factor in determining climbing success (e.g., Sanchez et al., 2010), the 27-item Competitive State Anxiety Inventory–2 questionnaire (Martens et al., 1990) was used to determine participants' levels of cognitive anxiety, somatic anxiety, and self-confidence prior to the start of the competition, using a 4-point Likert scale (1 = *not at all*, 2 = *somewhat*, 3 = *moderately so*, 4 = *very much so*). For the same reason, participants' physical states prior to data collection were gathered using Kleinert's (2006) Perceived Physical State Scale Questionnaire; this reliable and valid 20-item questionnaire assesses self-perceived states of activation, health, training, and flexibility on a 6-point Likert scale, ranging from 5 (*I totally agree*) to 0 (*I agree not at all*).

Perceived Exertion and Blood Lactate

Given that fatigue following climbing a boulder can negatively impact subsequent bouldering performance (Medernach et al., 2016), participants' perceived exertion was assessed following each boulder using Borg's rating of perceived exertion scale (Borg, 1982). Likewise, lactate levels following climbing can be indicative of local muscular fatigue (Draper et al., 2006). Therefore, after a 2-min recovery period following the climbing period at each boulder, 10 μL of capillary blood was collected from the hyperemic earlobe using a nonalcoholic cellulose swab. Lactate levels were measured with a calibrated Vario Photometer II (Diaglobal GmbH, Germany). Two measurements were completed for each sample (i.e., instrumental consistency), and the mean value was retained for deviations below 0.2 mmol/L; this was the case for all assessments.

Climbing Movement Repertoire

Sport-specific movement repertoire was determined by examining the participants' ability to identify the predominant climbing movements of the boulders prior to attempting them. Following Medernach, Henz, and Memmert (2024), participants were asked to tick the appropriate boulder type (see the Design of the Boulders section) from a list of four boulder categories: the strength type (i.e., boulders that primarily require a high level of finger strength), the athletic type (i.e., dynamic and powerful movements in which upper body power is decisive), the tricky type (i.e., boulders that comprise slow-paced and balancing climbing movements), and the parkour type (i.e., dynamic whole-body running and jumping movements).

Climbing Performance

Climbing performance parameters comprised (a) the number of successfully completed boulders, (b) the number of climbing attempts to complete the boulders, and (c) the number of failed climbing attempts. Consistent with IFSC rules, a successful completion was retained when participants achieved the marked finishing hold with both hands and in a controlled position. A failed climbing attempt was recorded each time participants fell out of the wall.

Climbing Strategy

The assessment of the participants' strategic planning skills included the following items: (a) the preview-time ratio, (b) the suitability of their climbing strategies, (c) adjustments they made to their initial strategies, and (d) strategy-performance factors. Specifically, the preview-time ratio was calculated as a percentage of the 5-min time limit for each boulder. It represents the amount of time participants spent previewing the boulders in order to process the visual sensory input and develop an appropriate climbing strategy.

Strategy suitability, climbing strategy adjustments, and strategy-performance factors were independently assessed by four climbing experts (European Qualifications Framework: Level 5, ≥14 years climbing experience, ≥25 IRCRA points, elite bouldering level) using video recordings. The intraclass correlation coefficient revealed high interrater consistency for strategy suitability ($r = .91$, $p < .001$) and strategy adjustments ($r = .92$, $p < .001$).

Drawing on the SFAC (i.e., suitability, feasibility, acceptability, competitive advantage) framework for strategic management originally proposed by Johnson and Scholes (1993), experts classified the climbing strategy participants used for each attempt as either unsuitable (1), feasible (2), or advantageous (3). This broad classification was intended to provide insight into the appropriateness of the climbing strategies participants used in their attempts. A climbing strategy was classified as "unsuitable" if the chosen action plan for linking hand and foot movements was inappropriate for successfully solving the boulder, such that motor execution caused a failed climbing attempt. A "feasible" climbing strategy led to the completion of a boulder, although the linking of hand and foot movements was not fully adequate, resulting in visibly uncontrolled or jerky movement execution. A climbing strategy was considered "advantageous" if the action plan for linking movements allowed climbers to perform movements efficiently, without uncontrolled or jerky movement execution, thereby resulting in no unnecessary movements and nonmovement times. The four experts observed all attempts made by the participants and provided ratings for each boulder. The mean scores of the four boulders were retained as the final scores.

Similar to the strategy suitability, experts also independently assessed the number of climbing strategy adjustments climbers made while attempting the boulders. A climbing strategy adjustment was retained each time participants had to interrupt movement execution as they failed to grasp a target hold; a climbing strategy adjustment was only retained when the adaptation (e.g., change of foot) resulted in a successful completion of the movement (i.e., without falling off the wall—this would have been retained as a failed climbing attempt). Similar to strategy suitability, the final scores were determined by averaging the mean scores provided by the experts for the four boulders.

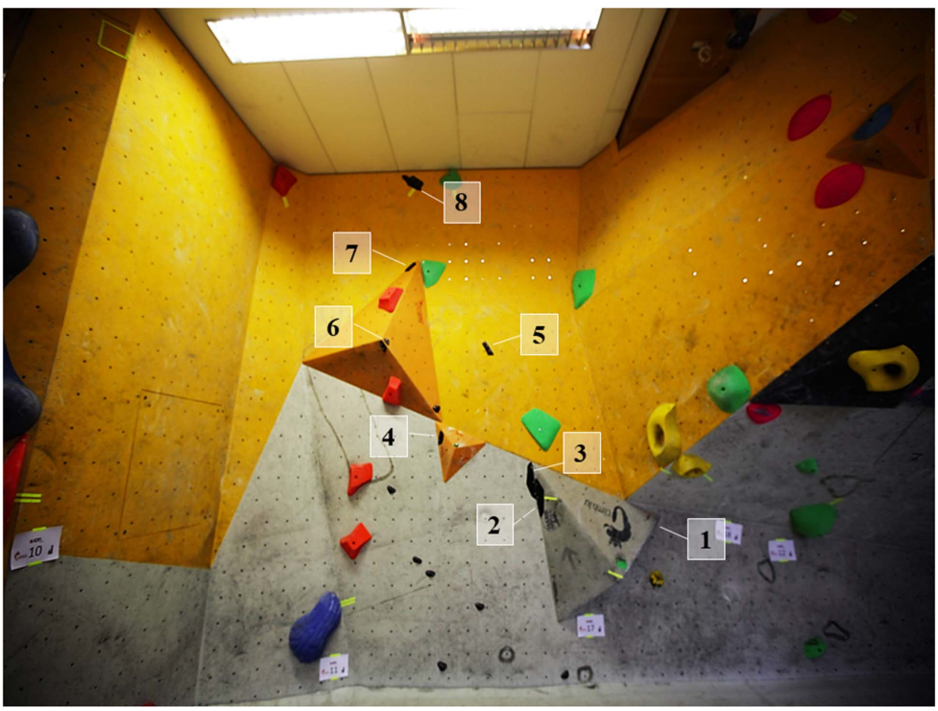
As climbing strategies may be associated with rehearsal (i.e., the more attempts climbers make, the better their strategy becomes), a strategy-performance factor was computed, combining climbing performance and strategy using the following equation: $\left(\frac{\sum_{i=1}^{n} \text{strategy adjustments} + 1}{\sum_{i=1}^{n} \text{number of completed boulders} + 1}\right) \times$ number of attempts. Low strategy-performance factors reflect better climbing strategies relative to climbing performance (i.e., completed boulders and number of attempts).

Furthermore, at the end of each climbing period (i.e., when climbers made no further attempts or the 5-min time limit had expired), participants were asked to indicate verbally (no/yes) whether they had a concrete climbing strategy prior to their first attempt at each boulder. Additionally, they were asked to indicate the number of adjustments they made to their initial climbing strategy during subsequent attempts at the boulders.

Design of the Boulders

Three expert routesetters (routesetting qualifications—European Qualifications Framework: ≥Level 3, ≥25 years climbing experience, ≥26 IRCRA points, elite bouldering level) were tasked with setting four novel boulders, categorized into four types: (a) a strength-type boulder, (b) an athletic-type boulder, (c) a tricky-type boulder, and (d) a parkour-type boulder (see Figures 1–4). The four boulders were rated 20–22 points on the IRCRA scale, indicating an advanced level of difficulty; the difficulty thus corresponded to the climbing ability levels of the participants. The intraclass correlation coefficient

Figure 1
The Strength-Type Boulder of the Study



Note. The boulder comprised eight handholds (marked with numbers) and was set on a 15° overhanging bouldering wall. The expert routesetters rated the boulder as advanced level with a difficulty of 20 International Rock Climbing Research Association points. The boulder ratings assigned by the routesetters using the RIC scale (i.e., 5-point Likert scale, ranging from 1 = *very low* to 5 = *very high*, to categorize climbing movements): Risk (2 points), Intensity (4 points), and Complexity (2 points). RIC = Risk, Intensity, Complexity. See the online article for the color version of this figure.

Figure 2
The Athletic-Type Boulder of the Study

Note. The boulder comprised 10 handholds (marked with numbers) and was set on a 60° overhanging bouldering wall. The expert routesetters rated the boulder as advanced level with a difficulty of 21 International Rock Climbing Research Association points. The boulder ratings assigned by the routesetters using the RIC scale (i.e., 5-point Likert scale, ranging from 1 = *very low* to 5 = *very high*, to categorize climbing movements): Risk (3 points), Intensity (5 points), and Complexity (3 points). RIC = Risk, Intensity, Complexity. See the online article for the color version of this figure.

was calculated to compare the difficulty of the boulders independently rated by the routesetters. The results revealed high interrater consistency ($r \geq .96, p < .001$), indicating that routesetters were consistent in their assessment of difficulty.

Statistical Analyses

Statistical analyses were conducted using IBM SPSS Statistics 29 (IBM Corporation, United States). Data are presented as mean values and standard deviations ($M \pm SD$). An α level of $p < .05$ (two-tailed) was used to determine statistical significance. Separate linear regressions were conducted to examine the effect of independent variables (e.g., climbing strategy) on dependent variables (e.g., climbing performance). *R*-squared (R^2) was calculated to determine the proportion of variance in the dependent variable that can be explained by the independent variable. Power analysis for separate regressions with one predictor indicated a coefficient of determination (R^2) of .219 for a sample size of 30 participants, a power ($1 - \beta$) of .80, and an α of .05. The Spearman's rank-order correlation coefficient was used to determine a significant relation between two variables.

Alongside regression analyses, an analysis of variance was conducted to determine differences of the means between the study groups. All variables were assessed for normality of distribution using the one-sample Kolmogorov–Smirnov test. Levene's test was used to verify the homogeneity of variance, and Bonferroni post hoc pairwise comparisons were calculated to determine between-group differences. Power analysis indicated an effect size $\eta^2 = .27$ for three study groups, a sample size of 30 participants, a power ($1 - \beta$) of .80, and an α of .05. The nonparametric Kruskal–Wallis one-way

Figure 3
The Tricky-Type Boulder of the Study

Note. The boulder comprised five handholds (marked with numbers) and was set on a vertical bouldering wall. The expert routesetters rated the boulder as advanced level with a difficulty of 20 International Rock Climbing Research Association points. The boulder ratings assigned by the routesetters using the RIC scale (i.e., 5-point Likert scale, ranging from 1 = *very low* to 5 = *very high*, to categorize climbing movements): Risk (4 points), Intensity (1 point), and Complexity (3 points). RIC = Risk, Intensity, Complexity. See the online article for the color version of this figure.

analysis of variance and the Mann–Whitney test were used when analysis of variance assumptions were violated. Eta-square was calculated and converted to *r* for indicating the effect sizes between the groups.

Transparency and Openness

To adhere to the Transparency and Openness Promotion guidelines, the article includes appropriate citation for all data and materials used consistent with the journal's author guidelines. Methods employed in the analysis and materials used for conducting the research are clearly and precisely documented. Data are accessible on the Harvard Dataverse (https://doi.org/10.7910/DVN/QMLLJA) for purposes of reproducing the results or replicating the procedure. Inclusion and exclusion criteria are outlined, and all measures are meticulously described.

Results

Personal Characteristics and Sport-Specific Background

As shown in Table 1, between-group differences for age, body weight, and height were nonsignificant. The three study groups also showed comparable grip strength scores, with a nonsignificant relation between the participants' grip strength performances (independent variable) and both their number of completed boulders ($b = 0.07$, $R^2 = .007$, $p = .668$) and their number of failed climbing attempts ($b = -0.001$, $R^2 = .004$, $p = .729$). Furthermore, between-group differences regarding

Figure 4
The Parkour-Type Boulder of the Study

Note. The boulder comprised six handholds (marked with numbers) and was set on a vertical bouldering wall. The expert routesetters rated the boulder as advanced level with a difficulty of 22 International Rock Climbing Research Association points. The boulder ratings assigned by the routesetters using the RIC scale (i.e., 5-point Likert scale, ranging from 1 = *very low* to 5 = *very high*, to categorize climbing movements): Risk (5 points), Intensity (2 points), and Complexity (3 points). RIC = Risk, Intensity, Complexity. See the online article for the color version of this figure.

the participants' IRCRA scores and their years of climbing experience were nonsignificant. Results indicated no significant relations between the participants' IRCRA scores and their years of climbing (independent variables), and both their number of completed boulders ($b = 0.34$, $R^2 = .097$, $p = .093$; $b = 0.03$, $R^2 = .005$, $p = .712$) and their failed climbing attempts ($b = -0.17$, $R^2 = .032$, $p = .345$; $b = -0.04$, $R^2 = .008$, $p = .630$).

In contrast, the TOP group reported having participated in more bouldering competitions prior to the study than the MID and BOT groups (see Table 1). Results revealed a significant relation between the participants' competitive bouldering experience (independent variable) and both their number of completed boulders, with $b = 0.07$ (0.004, 0.13), $R^2 = .145$, $F(1, 29) = 4.75$, $p = .038$, and their number of failed climbing attempts, with $b = -0.08$ (−0.14, −0.02), $R^2 = .242$, $F(1, 29) = 8.96$, $p = .006$.

Preperformance Mental and Physical States

The Competitive State Anxiety Inventory–2 reports showed no significant between-group differences for cognitive anxiety (TOP: 17.9 ± 2.9, MID: 18.4 ± 2.6, BOT: 18.6 ± 3.7, $p = .870$, $r = .10$), somatic anxiety (TOP: 15.3 ± 2.8, MID: 13.5 ± 3.0, BOT: 14.6 ± 2.2, $p = .327$, $r = .28$), and self-confidence (TOP: 25.3 ± 4.4, MID: 25.5 ± 4.8, BOT: 26.5 ± 4.1, $p = .813$, $r = .12$). The relations between the Competitive State Anxiety Inventory–2 scores (independent variables) and both the number of completed boulders ($R^2 \leq .010$, $p \geq .603$) and failed climbing attempts were also nonsignificant ($R^2 \leq .061$, $p \geq .187$).

Furthermore, preperformance activation (TOP: 3.4 ± 1.1, MID: 3.7 ± 0.8, BOT: 3.2 ± 0.9, $p = .468$, $r = .22$) and health states (TOP: 3.6 ± 1.2, MID: 4.4 ± 1.1, BOT: 4.1 ± 0.7, $p = .152$, $r = .32$) were similar across the study groups. Conversely, participants from the MID group (4.1 ± 0.7) reported better training states compared to those reported by the BOT group (2.9 ± 1.2, $p = .024$, $r = .52$). However, differences between the TOP group (3.7 ± 0.8) and both the MID ($p = .717$, $r = .26$) and BOT ($p = .186$, $r = .36$) groups were nonsignificant. Linear regression indicated nonsignificant relations between the participants' physical states (independent variables) and both their number of completed boulders ($R^2 \leq .034$, $p \geq .326$) and their failed climbing attempts ($R^2 \leq .038$, $p \geq .304$).

Perceived Exertion and Blood Lactate

The three study groups reported similar average postclimbing rating of perceived exertion values (TOP: 15.2 ± 0.9, MID: 15.1 ± 0.8, BOT: 15.8 ± 0.8, $p = .198$, $r = .34$). The relation between the rating of perceived exertion scores (independent variable) and both the number of completed boulders ($R^2 = .123$, $p = .058$) and the number of failed climbing attempts ($R^2 = .013$, $p = .547$) was nonsignificant. Likewise, results revealed comparable average postclimbing blood lactate levels across the study groups (TOP: 5.17 ± 0.9 mmol/L, MID: 4.87 ± 0.63 mmol/L, BOT: 5.06 ± 0.95 mmol/L, $p = .721$, $r = .16$), with no significant relations between blood lactate concentration (independent variable) and both the number of completed boulders ($R^2 = .003$, $p = .793$) and failed climbing attempts ($R^2 = .003$, $p = .835$).

Climbing Performance

As displayed in Table 2, the TOP group completed more boulders and needed fewer climbing attempts to complete the boulders than the MID and BOT groups. In addition, the TOP group performed fewer failed climbing attempts than the MID and BOT groups. Linear regression analyses revealed significant relations between the participants' ranking in the preceding qualification round (independent variable) and their number of completed boulders, with $b = -0.10$ (−0.13, −0.07), $R^2 = .620$, $F(1, 29) = 45.74$, $p < .001$; their number of attempts to complete the boulders, with $b = 0.06$ (0.03, 0.09), $R^2 = .381$, $F(1, 29) = 16.01$, $p < .001$; and their number of failed climbing attempts, with $b = 0.09$ (0.06, 0.11), $R^2 = .596$, $F(1, 29) = 41.31$, $p < .001$.

Climbing Strategy

Table 3 shows that the preview-time ratio was lower in the TOP group compared to the MID and BOT groups. While the three groups reported on average similarly often that they developed a concrete climbing strategy prior to their first attempts at the boulders, participants from the TOP group stated fewer adjustments to their initial climbing strategies than participants from the MID and BOT groups. The experts' assessments corroborate the self-reports by the participants; they identified on average fewer climbing strategy adjustments in the TOP group compared to the MID and BOT groups (see Table 3). Spearman's correlation coefficient revealed a significant correlation ($r = .865$, $p < .001$) between the number of climbing strategy adjustments reported by the

Table 2
Climbing Performances of the Three Study Groups

Variable (unit)	TOP group *M*	TOP group *SD*	MID group *M*	MID group *SD*	BOT group *M*	BOT group *SD*	Between group *F*/*H*	Between group *p*	Between group *r*
Completed boulders (number)	4.0	$0.0_{\text{MIDd}}^{\dagger}$	3.1	$1.1_{\text{BOTd}}^{\dagger}$	1.4	$1.1_{\text{TOPd}}^{\dagger}$	$H = 19.58$	<.001	.79
Climbing attempts to completion (number)	1.6	0.7_{MIDd}	2.7	$0.9_{\text{BOTc}}^{\dagger}$	3.5	$0.6_{\text{TOPd}}^{\dagger}$	$H = 12.19$	.002	.65
Failed climbing attempts (number)	1.3	$0.4_{\text{MIDd}}^{\dagger}$	2.8	1.0_{BOTc}	3.4	$0.9_{\text{TOPd}}^{\dagger}$	$F = 16.42$	<.001	.74

Note. Results are reported as mean ± standard deviation, followed by statistical comparisons between two groups using subscript characters, including the group being compared to ($_{\text{TOP}}$, $_{\text{MID}}$, $_{\text{BOT}}$) and letters denoting the effect size r ($_a r < .1$, $_b 1 \leq r < .3$, $_c 3 \leq r < .5$, $_d r \geq .5$). Between-group comparisons include either the analysis of variance (F) or Kruskal–Wallis (H) result, the p value, and the effect size r. TOP = top 10 ranked climbers; MID = 11–20 ranked climbers; BOT = bottom ten ranked climbers.
† $p < .05$.

Table 3
Climbing Strategies of the Three Study Groups

Variable (unit)	TOP group		MID group		BOT group		Between group		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*/*H*	*p*	*r*
Preview-time ratio (percentages[a])	13.8	$1.9_{\mathrm{MIDd}}^{\dagger}$	18.2	4.9_{BOTb}	22.4	$9.2_{\mathrm{TOPd}}^{\dagger}$	$H = 10.06$	.007	.52
Strategy before first attempt (score[b])	0.9	0.1_{MIDa}	0.9	0.2_{BOTb}	0.8	0.2_{TOPb}	$H = 1.07$	.587	.24
Strategy adjustments: Self-reports (number[c])	1.1	$0.7_{\mathrm{MIDd}}^{\dagger}$	2.5	0.6_{BOTc}	2.3	$0.6_{\mathrm{TOPd}}^{\dagger}$	$H = 13.37$	.001	.71
Strategy adjustments: By experts (number[d])	0.9	$0.7_{\mathrm{MIDd}}^{\dagger}$	2.5	0.7_{BOTa}	2.5	$0.6_{\mathrm{TOPd}}^{\dagger}$	$F = 19.55$	<.001	.77
Climbing strategy suitability (score[d])	2.7	$0.4_{\mathrm{MIDd}}^{\dagger}$	2.0	0.7_{BOTc}	1.5	$0.6_{\mathrm{TOPd}}^{\dagger}$	$H = 14.65$	<.001	.70
Strategy-performance factor (score[e])	2.1	$1.4_{\mathrm{MIDd}}^{\dagger}$	12.2	$10.0_{\mathrm{BOTc}}^{\dagger}$	27.6	$23.8_{\mathrm{TOPd}}^{\dagger}$	$H = 18.94$	<.001	.59

Note. Results are reported as mean ± standard deviation, followed by statistical comparisons between two groups using subscript characters, including the group being compared to ($_{\mathrm{TOP}}$, $_{\mathrm{MID}}$, $_{\mathrm{BOT}}$) and letters denoting the effect size *r* ($_{a}r < .1$, $_{b}1 \leq r < .3$, $_{c}3 \leq r < .5$, $_{d}r \geq .5$). Between-group comparisons include either the analysis of variance (*F*) or Kruskal–Wallis (*H*) result, the *p* value, and the effect size *r*. TOP = top 10 ranked climbers; MID = 11–20 ranked climbers; BOT = bottom ten ranked climbers.
[a] Amount of previewing time before physically attempting the boulders, reported as a percentage of the 5-min time limit. [b] Participants' average approval (0: no; 1: yes) of a precise climbing strategy for the four boulders. [c] Average number of the four boulders reported by the participants. [d] Average ratings from the experts (1: unsuitable; 2: feasible; 3: advantageous). [e] Ratio between strategy adjustments and number of completed boulders relative to the number of climbing attempts.
$^{\dagger}p < .05$.

participants and those assessed by the climbing experts. Linear regression indicated a significant relation between the participants' number of climbing strategy adjustments as rated by the experts (independent variable) and both their number of completed boulders, with $b = -0.91$ (-1.33, -0.50), $R^2 = .422$, $F(1, 29) = 20.42$, $p < .001$, and their number of failed climbing attempts, with $b = 0.95$ (0.66, 1.24), $R^2 = .617$, $F(1, 29) = 45.04$, $p < .001$. Furthermore, the climbing strategy suitability scores (see Table 3) were higher in the TOP group compared to the MID and BOT groups. In this context, the TOP group also demonstrated better strategy-performance factors than the MID and BOT groups.

Climbing Movement Repertoire

Prior to attempting the boulders, the TOP group (0.73 ± 0.3) was on average more successful in accurately assigning the prevailing climbing movements to the appropriate boulder type category than the MID (0.35 ± 0.2, $p = .008$, $r = .60$) and BOT (0.30 ± 0.3, $p = .003$, $r = .58$) groups, with $H = 10.09$, $p = .006$, $r = .62$. Linear regression indicated a significant relation between the participants' ability to accurately assign the climbing movements to the appropriate category (independent variable) and both their number of completed boulders, with $b = 1.80$ (0.24, 3.36), $R^2 = .166$, $F(1, 29) = 5.59$, $p = .025$, and their number of failed climbing attempts, with $b = -1.86$ (-3.13, -0.58), $R^2 = .242$, $F(1, 29) = 8.92$, $p = .006$.

Discussion

The purpose of the present study was to examine strategic planning in competitive bouldering to gain further insight into mechanisms underlying strategy proficiency among successful climbers. To that end, we examined during the semifinals of a national bouldering competition a series of climbing-related performance and strategic planning parameters, including the suitability of the competitors' climbing strategies, adjustments they made to their initial strategies, and their climbing movement repertoire. Major findings encompass a significant relation between climbers' ranking in the preceding qualifying round and their climbing performances in the semifinal examined—the higher ranked climbers from the TOP group completed more boulders, required fewer attempts to solve the boulders, and exhibited a lower number of failed climbing attempts compared to the lower ranked climbers from the MID and BOT groups. In addition, while the three study groups reported having developed precise climbing strategies prior to attempting the boulders, climbers from the TOP group had higher strategy suitability ratings, made fewer climbing strategy adjustments following their first attempts at the boulders, and demonstrated better strategy performances. Lastly, climbers from the TOP group were more successful in accurately assigning the prevailing climbing movements to the appropriate boulder type category than climbers from the MID and BOT groups.

Taken together, findings highlight that mastering competitive bouldering is associated with climbers' strategic planning relative to the climbing movements of boulders, their physical constraints, and their motor skills. Extending the pattern-matching paradigm to competitive bouldering, an extensive repertoire of climbing movements in particular accounts for more suitable climbing strategies, less time to generate climbing strategies, and fewer adjustments to initial climbing strategies among more successful competitors. The following sections discuss the findings of the study in relation to the hypotheses.

Strategic Planning Is Associated With Bouldering Performance (Hypothesis 1)

A key finding of this study was that higher ranked climbers needed a lower amount of the 5-min time limitation to preview the boulders and were more successful in developing suitable climbing strategies than lower ranked climbers—higher strategy suitability ratings and fewer climbing strategy adjustments support the assumption that climbers from the TOP group were more successful in developing appropriate strategies and creating action plans to link climbing movements. These findings confirm our Hypothesis 1 in that climbers who exhibited better competitive performance developed more suitable climbing strategies, needed less time to develop their climbing strategies, and required fewer adjustments to their strategies following initial climbing attempts than less successful climbers. Better strategy-performance factors observed among higher ranked climbers furthermore support the assumption that appropriate strategical planning is associated with bouldering performance.

Our assumption that strategic planning is a key determining factor in competitive bouldering is corroborated by previous research in sport climbing, highlighting psychologically based climbing aspects such as problem-solving ability, route finding, and route management as potentially better predictors of performance outcomes than physiological or biomechanical parameters (e.g., Giles et al., 2006; Morrison & Schöffl, 2007). Beyond bouldering and climbing, findings also align with research from sport domains with similar requirements, such as golf (e.g., Wang et al., 2020) and parkour (e.g., Strafford et al., 2021), emphasizing the pivotal role of cognitive-motor processes in achieving optimal performance.

However, as climbing expertise is typically related to multiple performance-determining factors (Sanchez et al., 2019; Saul et al., 2019), it is crucial to explore other potential factors, besides strategic planning, that may have contributed to better climbing performances among the TOP group. Specifically, although previous research has indicated that psychological states preceding climbing competitions may be a crucial factor in determining climbing success (e.g., Sanchez et al., 2010), findings from our study revealed nonsignificant relations between preperformance cognitive and somatic anxiety as well as self-confidence scores and both boulder completion and failed attempts. In addition, nonsignificant differences across the study groups in terms of self-perceived activation and health states provide further evidence that climbers in our study exhibited comparable preperformance psychological states. However, it is worth noting that previous research (e.g., Sanchez et al., 2019) had focused on sport climbing, while the present study examined bouldering. Indeed, the growth of each climbing discipline shall be accompanied with the development of ecologically valid, targeted research to best inform each discipline as needed.

It is also worth noting that all three study groups were characterized by similar personal characteristics and comparable sport-specific backgrounds. Indeed, nonsignificant effects between climbing performance and both various demographic as well as sport-specific variables (i.e., grip strength, IRCRA score, climbing experience, technical skills) suggest that these items are unlikely to primarily account for variations in climbing performance across the study groups. To exemplify, although the three study groups demonstrated comparable grip strength scores, the TOP group was more successful in solving the strength-type Boulder 1, indicating that superior climbing performance was not primarily related to finger strength. Nonsignificant relations between self-perceived training scores and both boulder completion and failed climbing attempts furthermore support the assumption of comparable strength and conditioning skills across the three study groups. Similar findings were also found for self-perceived exertion values and blood lactate levels post bouldering, with again non-significant relations between these variables and both boulder completion and failed climbing attempts.

In semifinals and finals of today's competitive bouldering, it is increasingly common that competitors possess comparable sport-specific qualities as well as technical and motor skills (Neumann, 2019). This trend is particularly associated with the continuous expansion of climbing facilities and the increasing number of climbing competitions over the past decade; both have contributed to a general improvement in training opportunities, so that a growing number of top climbers nowadays possess similar motor and technical skill levels. This has also influenced routesetting over the last decade, as routesetters have been increasingly obliged to explore new styles and design creative boulders that require surprising and original climbing strategies (Henz et al., 2024). As such, proficiency in competitive bouldering has shifted over the last 2 decades from the ability to climb purely physically and technically demanding boulders to the increasingly crucial role of problem-solving, particularly when planning and preparing ascents during boulder previewing (Medernach & Memmert, 2021; Neumann, 2019).

Notwithstanding, this does not mean that physical constraints, physiological skills, and psychological states can be neglected as determining factors for climbing performance (see Sanchez et al., 2019); they are just another aspect of a whole puzzle of sport-specific climbing skills and abilities. However, this explains that mastering competitive bouldering is particularly associated with strategic planning, which is inherently associated with increasingly complex and coordinative climbing movements in today's bouldering competitions (Henz et al., 2024; Neumann, 2019).

Strategy Planning Is Associated With Movement Repertoire (Hypothesis 2)

While the characteristics of modern climbing movements and an increasingly skilled field of competitors account for the growing relevance of strategic planning in competitive bouldering, the mechanisms underlying superior climbing strategy proficiency among more successful climbers require further attention. In this context, a major finding of this study was the significant relations between the participants' ability to accurately assign climbing movements to the appropriate boulder type category and both boulder completion and failed climbing attempts. In line with Medernach, Henz, and Memmert (2024), these findings confirm our Hypothesis 2 in that higher ranked climbers were characterized by a superior climbing movement repertoire compared to lower ranked climbers.

Findings from this study provide support for the theoretical concept that strategic planning of climbing ascents draws upon the repertoire of climbing movements. In fact, the process of strategic planning requires athletes to possess an understanding of the sport-specific context (Buekers et al., 2020). Such contextual understanding necessitates athletes to appropriately process sensory input and compare perceived stimuli with movement patterns stored in long-term memory. This enables them to identify characteristic climbing movements based on the arrangement of climbing holds and to subsequently devise potential climbing strategies (Medernach, Sanchez, et al., 2024). In this context, climbers exhibit similarities with other experts, such as chess grandmasters (Connors et al., 2011) or expert musicians (Sheridan & Kleinsmith, 2022), in that they rely on domain-specific movement patterns stored in long-term memory. This enables them to be more attuned to perceptual variables, to benefit from higher anticipatory decisions, and to recognize familiar movement patterns (Cowell et al., 2019; Roca & Williams, 2016). Accordingly, findings reinforce the conceptual framework of the matching theory associated with the movement repertoire paradigm by indicating that a broader repertoire of climbing movements is likely to explain superior strategic planning, corroborated by more suitable climbing strategies, less time to generate climbing strategies, and fewer adjustments to initial climbing strategies among more successful competitors. That is, an extensive climbing movement repertoire is crucial for making appropriate perceptual judgments of climbing capabilities (Whitaker et al., 2020), accurately interpreting task-relevant information (Sanchez et al., 2019), and identifying meaningful climbing movement patterns during boulder previewing (Medernach, Henz, & Memmert, 2024).

Although our study included only male climbers with no a priori power analysis (i.e., the relatively high effect sizes and *R*-squared values substantiate the statistical robustness) and that findings partly draw on self-reports, further findings from this study underpin this assumption. Firstly, climbers from the TOP group exhibited a lower preview-time ratio than climbers from the MID and BOT groups. Consistent with previous research (Medernach & Memmert, 2021), these findings indicate that climbers from the TOP group needed less time to process visual sensory input and thus identify suitable climbing strategies during previewing. Secondly, fewer climbing strategy adjustments among the TOP group emphasize that top-ranked climbers had to interrupt movement execution less often, while participants from the MID and BOT groups performed more often erroneous hand and feet actions that obliged them to adapt their strategies to compensate for misinterpretations during route previewing. Lastly, although the study groups did not differ in terms of climbing years, the TOP group reported longer competitive bouldering experience, which furthermore supports the assumption of a more extensive repertoire of climbing movements among higher ranked climbers.

Previous research from sport climbing supports the assumption that a domain-specific movement repertoire is crucial for decoding sensory information and exploring potential climbing strategies. Bläsing et al. (2014), for instance, examined the impact of climbing ability on cognitive activation of grasping actions. The authors found that climbers exhibited associated grasping postures when perceiving different climbing holds, while nonclimbers did not. In addition, Ferrand et al. (2006) examined impediments to successful climbing performance as perceived by elite competitors, who described lack of climbing route knowledge as a major self-handicap in climbing competitions. Moreover, Sanchez et al. (2019) surveyed expert climbing coaches on parameters that predict sport climbing performance. Among many determining factors, experts identified a domain-specific movement repertoire as a crucial performance factor in sport climbing. Experts thus emphasized the pivotal role of contextual understanding and thus the relevance of an extensive climbing movement repertoire in interpreting climbing movements and devising potential climbing strategies based on the arrangement of climbing holds. However, future research must address how training regimens can deliberately foster climbing movement repertoire and domain-specific creativity to optimally prepare climbers to the characteristics of modern climbing movements.

Conclusion

Among multiple determinants of climbing performance, findings from this study emphasize that mastering competitive bouldering is associated with climbers' strategic planning abilities relative to climbing movements of boulders, their physical constraints, and their motor skills—more successful competitors had higher strategy suitability ratings, made fewer climbing strategy adjustments following their first attempts at the boulders, and demonstrated better strategy performances than less successful competitors. The relevance for competitors of being able to quickly develop appropriate climbing strategies is associated with the characteristics of modern climbing movements and an increasingly skilled field of competitors. Findings furthermore reinforce the movement repertoire paradigm and the inherently related conceptual framework of the matching theory as major mechanisms underlying superior strategic planning among more successful climbers—similar to chess players or musicians, an extensive repertoire of climbing movements seems to account for more suitable climbing strategies, less time to generate climbing strategies, and fewer adjustments to initial climbing strategies among more successful competitors.

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