Ann Appl Sport Sci, 12(01): e1323, 2024.
http://www.aassjournal.com; e-ISSN: 2322–4479; p-ISSN: 2476–4981. 10.61186/aassjournal.1323

ORIGINAL ARTICLE

Witty SEM System and Cognitrom Assessment System: Novel Technological Methods to Predict Performance in Youth Rock Climbers

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Submitted November 07, 2023; Accepted in final form January 17, 2024.

ABSTRACT

Background. Every new climbing route presents a novel cognitive and motor challenge. Assessing neurocognitive function in competitive rock climbers is an emerging area of research that may be utilized to assess and predict performance. **Objectives.** The aim was to compare two systems that evaluate cognitive function in their prediction of climbing performance in 17 youth elite climbers (all elite climbers from Romania who met the inclusion criteria). **Methods.** We utilized and compared two systems, one on a computer system that is operated with the subject not engaged in a motor task (Cognitrom) and one during a motor task (Witty SEM), more similar to neurocognitive challenges faced while climbing. We examined selected outcome measures from each system (spatial skills and reactivity with Cognitrom) and selected motor-cognitive outcome measures from Witty SEM (cognitive agility, visual memory, and visual processing speed). **Results.** From the Cognitrom, spatial skills were negatively associated with red-point performance in 21.7% of the cases. From Witty SEM, cognitive agility positively predicted red-point performance in 52.1% of the cases. Climbing experience and visual memory errors predict red-point climbing performance in 79.2% of the cases. Visual memory errors were negatively associated with climbing performance. **Conclusion.** Our results showed that neurocognitive parameters measured with Witty SEM were more strongly associated with climbing performance than the Cognitrom system.

KEYWORDS: ***Spatial Orientation, Cognition in Climbing, Cognitrom Battery, Cognitive Agility, Visual Memory, Reactivity in Climbing.***

INTRODUCTION

Climbing was included in the Tokyo 2020 Olympic Games and has grown significantly in popularity in the last years (1). Athletes practice in outdoor environments (real rock) and in indoor environments (artificial walls) (2). Climbing has three different disciplines: lead-climbing (climbing with rope protection), bouldering (climbing on shorter routes with mattress floor protection), and speed-climbing (climbing on a standardized route with specific holds and measures the time for ascending) (3). In lead-climbing, climbers attach a rope to anchors that are previously placed on the wall or on the rock, as they progress towards the top of the route (4). In bouldering, climbers need mattress floor protection to protect against injury in case of

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falling (4). In speed climbing, climbers had to reach the top of the route as soon as possible (4). When the climber completes the route on the first try without any previous practice or any useful information about the route is considered an on-sight (5). When a climber completes the route from the first try having previous information about the route (such as the plan of ascending after watching others climb the route before them) it is considered a flash (5). After failure on the first try, any following try that leads to completing the route is considered a red-point (5). In addition, climbing red-point usually means climbing at the limit of one's abilities (6).

Climbing is an example of a sport where athletes plan motor sequences to ascend a route composed of different arrays of hand and foot holds (7). It is considered a unique perceptual and cognitive skill because climbers have to integrate complex, yet stable arrangements of the environmental characteristics (the different holds) similar to mind sports, such as chess, go game, or bridge game (8). Despite the stable environment in which a climber acts, their movement through the space (especially on new routes that they have never climbed before) is thought to be highly dynamic (7). Climbers perform these cognitive tasks while engaging in a sports activity where they must accommodate their physical capabilities in relation to environmental aspects (8).

Rock climbing is not characterized by reactivity in fine motor tasks (9). Hands and feet move independently in some well-aligned temporal and spatial movements (10). Every new climbing route requires new combinations of visual, spatial, and motor processing, which is in contrast to other cyclic sports (like running or cycling) where the motor task is performed repeatedly or to other sports (like gymnastics or ice skating) where some trained elements are put together (10). On the other hand, accumulated competitive experience develops not only athletic techniques, but also mental skills such as attention, mental stability, motor memory, and work memory (11).

There are several studies that analyzed the cognitive function of a climber. Several studies explained that climbing improves physical fitness, muscle strength, visual-motor coordination, balance, endurance, sensory perception, and mobility (12). Sport climbing also has a beneficial effect on the ability to search for new solutions and spatial orientation (13). Spatial skills are important for elite climbers because they need to properly control their center of mass while ascending toward the top of the route (10). A better spatial orientation will lead to the minimization of jerky movements, and more smoothly connected moves which will lead to efficient climbing (14). Cognitive agility refers to the ability of an athlete to easily move back and forth between openness and focus, in highly dynamic decision-making contexts, such as continuous postural instability (15). The neurocognitive functioning of sports climbers manifests with faster recognition and differentiation of tactile information, better spatial perception, and better movement memory (8). The climber needs to have the ability to look through the route, analyze the hardest parts of the route and decide where are the places to rest, to use chalk, to plan for alternatives when entering the harder parts of the route (16). Moreover, if a cognitive task interferes with a cyclical and almost automatic activity such as walking, we expect much greater interference for a physical activity that requires increased attention such as climbing, where the athlete is in a continuous postural instability (17). Reactivity skills were related to lead climbing performance, the number of errors in the complex reaction time test predicting on-sight and red-point performance (18). Moreover, lead-climbing and bouldering are not performed under time pressure, but a better reaction time will lead to faster activation of grasping actions which will lead to better athletic performance (19). Reaction time is an important skill for speed climbing (20). Visual memory, problem-solving skills, visualization, anxiety, and stress management are considered better predictors for climbing performance in comparison with biomechanical variables (21). Elite sports performance is linked to enhanced cognitive functions like attention, decision-making capacity, and working memory (22).

The importance of cognitive training is believed to be part of the tactical preparation of a climber (23). Tactical training of a climber means developing skills for choosing the efficient climbing speed during ascending, a better visualization, having a strategy for ascent planning, identifying the best places for resting and for securing anchors during the climb, creativity, and good decisional capacity (23).

There are many computerized digital assessment technologies and training instruments that evaluate several visual, cognitive, and sensory-motor skills in sports such as Witty SEM technology, Cognitrom assessment technology, Senaptec Sensory Station, Sports Vision Performance, Visual Edge Performance Trainer (24, 25).

Cognitrom assessment technology is a Romanian National validated test battery that contains computerized psychological tests. The battery measures: cognitive skills, non-cognitive skills, personality traits, and emotional traits. Some of the measured cognitive skills are work memory, cognitive inhibition, attention, vocabulary, syntax, calculus, mathematic rationale, spatial orientation, detail perception, reactivity skills, and decisional capacity. The tests are applied on a computer, in a laboratory setting (26). Cognitrom assessment technology was previously tested on elite climbers and analyzed spatial skills and reactivity skills, concluding that image generation has a negative effect on both on-sight performance and red-point performance (27). This suggested that a high level of image generation, as a spatial skill, can lead to overstimulation, which can lead to failure in the moment of a physical or mental breakdown during the climb (27). In addition, when analyzing reactivity skills with Cognitrom assessment technology on elite climbers, the results were that performance did not correlate with any of the reaction times measured (27).

The Witty semaphore system (Microgate, Italy) is composed of a LED matrix that displays different colors, numbers, and characters (28). The system is composed of 10 tripods (or semaphors) and can display several symbols (letters and images) and 3 colors (green, blue, and red). The witty SEM system is used for specific training for reactivity, agility, coordination skills, and motor-cognitive abilities (28). The agility tests measured with Witty are designed to evaluate complex processes of motor response to visual stimuli (28). This system can stimulate coordination capacity and reaction time (28). The Witty system can develop sensory-motor skills, improving the economy of motor tasks by improving the relationship between stimulus – processing the stimulus – decisional process – strategic processing – movement (28).

Witty SEM has the advantage that the researcher can add the motor aspect in addition to evaluating cognitive skills such as attention (with divided attention test, double decision test, mixed signals test), brain speed (with hawk eye test and eye for detail test) and intelligence (with juggle test) (28). Red A test measures cognitive agility, by having to rapidly analyze all the visual stimuli and distinguish the semaphor that has a specific letter on it, with the same color as the others (28). Hawkeye test challenges visual precision by asking to locate specific symbols (planes) in their peripheral vision so it measures visual processing speed (28). Eye for detail test measures visual memory (28). Because these tests evaluate cognitive variables in motor tasks, we further named them as motor-cognitive variables. Processing speed and visual memory are parts of cognitive development and can influence the interpretative process of individuals (29).

Several studies have examined athletes with Witty SEM technology. This technology was used as an evaluation method for examining reactive agility in 30 junior tennis players (30). Basketball players were examined with Witty SEM correlating the results of the Y-shaped agility test with the results of the agility test measured with Witty SEM technology (31). A similar study was performed on handball players (32). Another study demonstrated differences based on age in reactive agility, speed, and change of direction speed between adolescent soccer players (33). On the other hand, Witty SEM technology was used also as a training method: researchers used it for implementing a cognitive training program on 24 car racing drivers (34). Their result was that the experimental group had better results at some cognitive tasks measured with the Vienna test system than the control group, having higher accuracy and/or shorter reaction time. Their conclusion was that Witty SEM technology was efficient in inducing benefits on some cognitive performance indicators, so it can have an important contribution to car drivers' physical and mental preparation. Mental preparation and reducing physical tension are considered key factors in sports (35).

To the best of our knowledge, this is the first study that evaluated cognitive performance for elite youth climbers with two novel technological methods: the Cognitrom assessment system and the Witty SEM system. Another innovation came from evaluating a specific group of athletes, analyzing all elite youth climbers from Romania who are part of the National Youth Climbing Team.

MATERIALS AND METHODS

Research objective. Taking into account the issues discussed above, we applied Witty SEM technology and Cognitrom assessment technology on elite climbers. We analyzed some motor-cognitive variables with Witty SEM technology: cognitive agility, visual processing speed, and visual memory. These variables were measured in a motor activity. We analyzed also some cognitive variables with Cognitrom assessment system: reactivity and spatial orientation. These variables were measured in laboratory conditions. The research question was whether climbing performance is predicted differently by cognitive variables compared to motor-cognitive variables. The aim was to compare two systems that evaluate cognitive function in their prediction of climbing performance in 17 youth elite climbers (all elite climbers from Romania who met the inclusion criteria).

To the best of our knowledge, this is the first study that presents the tests that can be applied with Witty SEM technology and there are very few studies that used this technology in sports (30–34). Furthermore, this is the first study that described and applied the Witty SEM technology in sport climbing. Moreover, we presented a specific protocol for evaluating sport climbers with the Witty SEM system, describing the setup and the useful tests in relation to their performance. On the other hand, we tested Cognitrom assessment system that evaluates cognition in sport climbing athletes.

Research hypotheses.

- We assumed that motor-cognitive variables can predict better climbing performance in comparison to cognitive variables
- We assumed that visual memory is a critical skill for on-sight performance
- We assumed that cognitive agility, visual memory, and spatial skills are critical for red-point performance

Participants. Romanian climbing training is very much based on the physical and technical components of the athlete's athletic preparation. Maybe because of this reason, Romanian climbers do not have the best results at International competitions in comparison to other athletes. To this end, we evaluated only the climbers that participated in National and International competitions, in order to evaluate their cognitive preparation. For International competitions, even if the route setters refrain from grading routes from qualification, semi-finals, or finals, it is believed that the level is elite, around 7c+ to 8b+.

The study was conducted on 17 youth climbers including 10 males and 7 females, with ages between 13 and 20 years old (M=16.59; SD=2.09). As for climbers' scholar background, 4 climbers were in middle school, 8 were in high school and 5 were in the first year of University.

The first inclusion criterion was: age over 12 years old and lower than 21 years old, analyzing only youth climbers. The second inclusion criterion was that every climber had a minimum of 3 training sessions per week. The third inclusion criterion was for them to be advanced climbers, as defined by the International Rock Climbing Research Association (IRCRA) (36), with the male athletes who climbed at least 7a+ and female climbers who climbed at least 6c (according to the French scale). The minimum grade criteria were recorded to be at least on a red-point lead route performed in the last year before enrolling into the study. The fourth inclusion criterion was that the climber had participated in at least one national competition in the last year before enrolling in the study. We tried to analyze the best youth climbers from Romania, enrolling the entire National Youth Climbing Team.

This research was conducted under the auspices of the Doctorate School of the National University of Physical Education and Sports from Bucharest. The studies involving human participants were reviewed and approved by the Ethical Committee of the National University of Sport and Physical Education, Bucharest, Romania (no. 394/02.11.2022). Written informed consent to participate in this study was provided by the participant's legal guardian/next of kin. For athletes under 18 years old, written consent for participating in the study was obtained from their parents and from their principal coach. For athletes over 18 years old, written consent was obtained from the participants. Written informed consent has been obtained from the climbers in photos to publish this paper. Participant's confidentiality was maintained and the results from their own evaluation were shown only to each participant.

Instruments. The factual data collected were: age, school background, gender, climbing experience, and climbing performance. Climbing performance was divided into on-sight performance and red-point performance and further converted into Watts' scale, so it can help the statistical analysis (37).

The selected instruments were chosen based on the research question, in order to see how some cognitive skill can predict climbing performance. The cognitive skills were evaluated in two different situations: one in a static environment, in laboratory conditions, and the second in a dynamic environment, in a more sport-specific motor task.

The first digital technology that we used was the Cognitrom Assessment System (CAS++, Cluj-Napoca, Romania) to complete 2 scales for cognitive skills: reactivity and spatial skills (26). This technology was used because of the lack of cognitive skills evaluation technologies that were previously validated in the Romanian population.

1) The spatial skills scale included three subtests that measured mental image-transformation skills, spatial orientation, and image generation skills. According to the Cognitrom methodology, the spatial skills function measured the ability to generate, retain, and transform visual images, but also manipulation and organization of spatial information.
   - Mental image transformation measures the subject's ability to mentally transform images. The subject saw an image with 10 cubes in a specific geometric form. Next to this image, there were 4 more geometric forms. The subject had to select a geometric form that was identical to the first one but in a rotated way.
   - The spatial orientation test measured the subject's ability to orient in space. They had to analyze an image composed of some geometric figures and choose out of 4 options the one that had the same arrangement of geometric figures but seen from another angle.
   - The image-generation test measured the subject's ability to mentally generate images by composing others. The subjects had two images with squares that they saw for 5 seconds. Then they had to superimpose the two images in their mind and choose the correct one from a series of 4 options.
2) The reactivity scale included three subtests that measured simple reaction time, choice reaction time, and memory access reaction time. According to the Cognitrom methodology, the reactivity function measures the ability to respond quickly (with the hand, finger, or foot) to a stimulus (light, sound, image) when it appears. It indicated both the reaction speed and the information processing speed.
   - Simple reaction time measured the subject's speed of answering when seeing a visual stimulus. The subject had to press on space when the visual stimulus appeared.
   - Choice reaction time measured the subject's speed of answering the correct answer between alternatives. The subject saw for 5 seconds a group of 5 geometric figures. If the square and the circle were one next to another, they had to press a certain button; if the square and the circle were not next to each other, they had to press another button.
   - Memory access reaction time measured the subject's speed of recalling information from their memory. The subject saw 6 letters on the screen for 5 seconds, then a new letter appeared on the screen, and had to choose whether the last letter appeared or not within the 6 first letters.

The second digital technology that we used was the Witty SEM system by Microgate (Italy) (with 10 tripods) to complete 3 tests for measuring motor-cognitive skills. This technology was used because it evaluates cognitive skills, but in a specific sportive environment. The witty SEM system has the advantage of evaluating athletes in a more sport-specific context. We used 3 tests: eye for detail, hawk eye, and red A (see Figure 1 for an example). We used 10 telescopic tripods, with a setting that resembled the start-up position from a climbing boulder: with 4 starting points (2 for hands and 2 for feet- semaphors B, H, E, and D) and 6 more tripods that resembled possible future holds that the climber had to touch (see Figure 1 for an example) (28).

- Red A test measured cognitive agility. The athlete had 20 cognitive-motor tasks. On the 10 tripods appeared 10 different red stimuli (letters, numbers, or symbols) and the subject had to touch the tripod that showed a little red „a". The output of the test was the total time for completing the 20 tasks (see Figure 2 for an example).
- Hawkeye test measured visual processing speed. The athlete had 35 cognitive-motor tasks. On the 10 tripods appeared 9 green stimuli (represented by green planes) and only one red plane at the same time for 1 second and then all of the stimuli disappeared. The subject

had to touch the tripod that showed the green plane. The output of this test was: the total time for realizing the entire task (visual processing speed) and the number of errors (visual processing errors) (see Figure 3 for an example).

- Eye for detail test measured visual memory. The athlete had 18 cognitive-motor tasks. On three of the 10 tripods, consecutively for 1 second each, 3 visual stimuli were shown, 2 of them being identical. The athlete had to touch the 2 tripods that were similar. The output of this test was: the total time for completing the entire task (visual memory) and the number of errors (visual memory errors) (see Figure 4 for an example).

Procedure. The evaluation with the Cognitrom Assessment system took place in a laboratory, where there was only one climber and one of the researchers. The evaluation with the Witty SEM technology took place at the National University of Physical Education and Sport in Bucharest. At the motor-cognitive testing participated more climbers (from 2 to 5 per session).

Variables. The analyzed variables were: age, school background, climbing experience, on-sight performance, red-point performance, mental-image transformation, spatial orientation, image generation, simple reaction time, choice reaction time, memory access reaction time, cognitive agility, visual processing speed, visual processing errors, visual memory, visual memory errors.

Statistical analysis. The statistical analysis was performed in the SPSS program using: descriptive statistics analysis, correlation analysis, simple regression, multiple regression, and moderation analysis. The aim of the study was to examine the influence of the cognitive variables on performance in comparison with the influence of the motor-cognitive variables on performance. To this end, we conducted several regression analyses, based on the significant correlations. Because we analyzed cognitive skills and motor-cognitive skills, we analyzed whether gender and school background had any influence on the prediction of climbing performance using moderation analysis using PROCESS v3.5 by Andrew Hayes, model 1 (38).

Figure 1. Set-up of the semaphors resembling a starting position in a boulder problem.

Figure 2. Red A test.

Figure 3. Hawkeye test.

Figure 4. Eye for detail test.

RESULTS

The descriptive statistics for the measured variables are detailed in Table 1.

Correlation analysis. On-sight performance correlated with: climbing experience (p=0.02; R=0.688; R2=0.473), visual memory errors (p=0.013; R=-0.645, R2=0.41), cognitive agility (p=0.001; R=0.769; R2=0.591).

Red-point performance correlated with: climbing experience (p=0.002; R=0.700; R2=0.490), image generation (p=0.034; R=-0.515; R2=0.265), visual memory errors (p=0.025; R=-0.593; R2=0.351), cognitive agility (p=0.001; R=0.747; R2=0.558).

There were no significant correlations between climbing performance and reactivity variables.

There were no significant correlations between climbing performance and visual processing speed (measured with the hawk eye test of Witty SEM).

Regression analysis.

A. 1. Predicting on-sight performance based on cognitive variables.

Neither of the cognitive variables did not correlate with on-sight performance.

A.2. Predicting on-sight performance based on motor-cognitive variables and experience.

The first regression analyzed the influence of climbing experience (as the independent variable) and motor-cognitive variables (visual memory errors and cognitive agility as independent variables) on on-sight performance (as the dependent variable). We ran a multiple regression analysis, using the Backward method. Table 2 explains the model summary for the first regression.

Table 3 presents the coefficients for the first regression.

The first regression explained that the variance on-sight performance is predicted in 81.3% of the cases by the variance of climbing experience (positively, B=0.162) and number of errors at the eye for detail task (negatively, B=-0.656). In other words, on-sight performance is positively influenced by experience and negatively influenced by a number of errors in the visual memory task.

Table 1. Descriptive statistics of analyzed variables

	Minimum	Maximum	Mean
Age	13	20	16.65±2.09
Climbing experience	1	12	6.94±3.01
On-sight performance	2.25	4.75	3.25±0.80
Red-point performance	2.75	5.75	4.03±0.91
Mental images	10	18	13.65±2.67
Spatial orientation	12	18	15.65±2.06
Image generation	7	13	10.65±2.12
Simple reaction time	221	410	273.82±55.27
Choice reaction time	633	1600	1052.06±315.77
Memory access reaction time	761	2413	1101.88±375.05
Visual memory	0.13	0.36	0.27±0.08
Visual memory errors	1.00	3.00	2.64±0.63
Visual processing speed	0.03	0.08	0.05±0.01
Visual processing errors	1.00	6.00	3.93±1.38
Cognitive agility	51.34	78.00	60.69±9.13

Table 2. Model summary for on-sight performance predicted by climbing experience and motor-cognitive variables

Model Summary[c]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F
1	0.925[a]	0.856	0.813	0.348	19.850
2	0.917[b]	0.841	0.813	0.349	29.172

a. Predictors: (Constant), climbing experience, visual memory errors, cognitive agility.
b. Predictors: (Constant), climbing experience, visual memory errors.
c. Dependent Variable: on-sight performance.

Table 3. Coefficients for climbing experience and motor-cognitive variables that predict on-sight performance

Coefficients[a]											
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
2	(Constant)	4.004	0.505		7.933	0.000					
	Visual memory errors	-0.656	0.156	-0.515	-4.202	0.001	-0.645	-0.785	-0.505	0.961	1.040
	Climbing experience	0.162	0.030	0.665	5.430	0.000	0.766	0.853	0.652	0.961	1.040

a. Dependent Variable: on-sight performance.

B.1. Predicting red-point performance based on cognitive variables.

The second regression analyzed the influence of cognitive variables (image generation as the independent variable) on red-point performance (as the dependent variable). We ran a simple regression analysis. The model summary explained that the variance of red-point performance is predicted in 21.7% of the cases by the variance of the image generation variable (negatively, p=0.034, B=-0.220). In other words, red-point performance is negatively influenced by image generation.

B.2. Predicting red-point performance based on motor-cognitive variables.

The third regression analyzed the influence of motor-cognitive variables (visual memory errors and cognitive agility as independent variables) on red-point performance (as dependent variable). We ran a multiple regression analysis, using the Backward method. Table 4 explains the model summary for the third regression.

Table 5 presents the coefficients for the third prediction.

The third regression explained that the variance red-point performance is predicted in 52.1% of the cases by the variance of cognitive agility (positively, B=0.076). In other words, red-point performance is positively influenced by cognitive agility.

B.3. Predicting red-point performance based on motor-cognitive variables and experience.

The fourth regression analyzed the influence of climbing experience (as the independent variable) and motor-cognitive variables (visual memory errors and cognitive agility as independent variables) on red-point performance (as the dependent variable). We ran a multiple regression analysis, using the Backward method. Table 6 explains the model summary for the fourth regression.

Table 7 presents the coefficients for the fourth regression.

The third regression explained that the variance red-point performance is predicted in 79.2% of the cases by the variance of climbing experience (positively, B=0.196) and number of errors at the eye for detail task (negatively, B=-0.668). In other words, red-point performance is positively influenced by experience and negatively influenced by a number of errors in the visual memory task.

Moderation analysis. Because we analyzed the influence of some cognitive skills on performance, we had to take into account the possible influence of gender and school background. To this end, we introduced gender and school background as moderators for the relationships between selected variables and did a moderation analysis. The only significant moderation relation was that school background did influence the relation between visual memory errors and on-sight performance (p=0.05) (Figure 5).

From Figure 5 we saw that the regression slope for the relation between the motor-cognitive variable and on-sight performance differs depending on school background. For athletes that had a lower school education (middle school level) the slope regarding the number of errors reported to on-sight performance in steeper than for the athletes with high school education, which is even steeper than for the athletes who are in University. So the influence that the number of errors made in the eye for detail test has on the on-sight performance is different depending on the educational level.

Table 4. Model summary for red-point performance predicted by motor-cognitive variables

Model Summary[c]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F
1	0.785[a]	0.616	0.546	0.626	8.806
2	0.747[b]	0.558	0.521	0.643	15.122

a. Predictors: (Constant), cognitive agility, visual memory errors.
b. Predictors: (Constant), cognitive agility.
c. Dependent Variable: red-point performance.

Table 5. Coefficients for motor-cognitive variables that predict red-point performance

Coefficients[a]											
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
2	(Constant)	-0.468	1.198		-0.391	0.703					
	Cognitive agility	0.076	0.020		3.889	0.002	0.747	0.747	0.747	1.000	1.000

a. Dependent Variable: red-point performance.

Table 6. Model summary for red-point performance predicted by climbing experience and motor-cognitive variables

Model Summary[c]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F
1	0.913[a]	0.834	0.785	0.431	16.778
2	0.908[b]	0.824	0.792	0.423	25.796

a. Predictors: (Constant), climbing experience, visual memory errors, cognitive agility.
b. Predictors: (Constant), climbing experience, visual memory errors.
c. Dependent Variable: red-point performance.

Table 7. Coefficients for climbing experience and motor-cognitive variables that predict red-point performance

Coefficients[a]											
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
2	(Constant)	4.548	0.612		7.437	0.000					
	Visual memory errors	-0.668	0.189	-0.456	-3.534	0.005	-0.593	-0.729	-0.447	0.961	1.040
	Climbing experience	0.196	0.036	0.701	5.438	0.000	0.790	0.854	0.687	0.961	1.040

a. Dependent Variable: red-point performance.

DISCUSSION

The present study examined some cognitive variables (spatial skills and reactivity using Cognitrom assessment system) and some motor-cognitive skills (cognitive agility, visual processing speed, and visual memory using Witty SEM technology) in youth elite climbers. We analyzed their influence on climbing performance with differences between on-sight and red-point performance. We conducted 4 regression analyses to examine the influence of cognitive variables on performance in comparison with the influence of the motor-cognitive variables on performance. The aim of the study was to see the differences in predicting performance in climbing between cognitive laboratory skills and motor-cognitive skills. We wanted to test whether measuring some cognitive skills in a motor task can predict better sports performance than measuring cognitive skills in general.

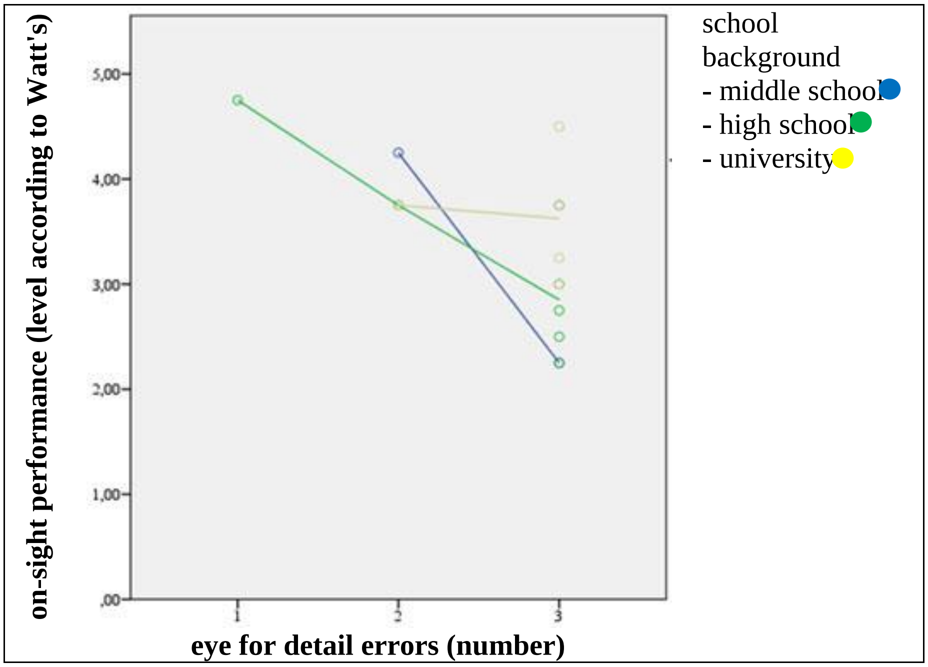

Figure 5. Influence of school background on the relationship between visual memory errors and on-sight performance.

Regarding cognitive skills, on-sight performance was not influenced by any of the cognitive variables that we tested (reactivity or spatial skills). Red-point performance is negatively influenced by image generation (one of the spatial skills). When the image generation ability increases, the red-point performance decreases. When a climber has a high image generation ability, their creativity in finding solutions for resolving the hardest part of the route increases. This ability can be a good skill when making the visualization on the ground. But, during the ascent, while the climber is physically and mentally tired, a high image generation combined with high creativity can overstimulate the climber's mind and can lead to failure (39, 40).

Regarding motor-cognitive skills, both on-sight and red-point performance are influenced by cognitive agility and visual memory. When a climber has a high cognitive agility, their performance increases. When a climber makes many errors in the visual memory test, their performance decreases. In climbing, the athlete is in a continuous change of the environment and has to continuously adapt to the new information they get from the holds, so the ability to switch attention from focus and openness is a critical skill. We concluded that cognitive agility and visual memory are key factors for performance in climbing.

When analyzing red-point performance, the prediction based on cognitive variables (image generation) was 21.7%. The prediction based on motor-cognitive variables (visual memory errors and cognitive agility) was 52.1%. Thus, the prediction of red-point performance based on motor-cognitive variables is higher than only on cognitive variables. We concluded that evaluating cognition in a motor task is more effective in predicting climbing performance than evaluating cognition in laboratory conditions. In addition, when adding climbing experience to the prediction model for red-point performance, the variance raised to almost 80% (79.2%), which is in line with other studies that demonstrated that experience predicts performance in any sport (41).

One conclusion from the correlation analysis was that the hawk eye test was not specific for evaluating performance in climbing. Hawkeye test was not specific probably due to the lack of applicability in climbing, hawk eye technology generally being used in ball tracking sports (42). We conclude that visual processing speed is not a key factor in climbing. In addition, even though Witty SEM uses these cognitive tests (hawk eye, eye for detail, and red A) for evaluating speed, precision of vision, and agility, we did not find any correlation with the reactivity tests from Cognitrom assessment system for this research group. This concludes that reactivity is not a key factor in climbing when analyzing bouldering and lead climbers.

Recent studies were performed to assess Witty SEM as an evaluating technology for agility, but also as a cognitive training method. Those studies were performed on several sports such as tennis (30), basketball (31), handball (32), and football (33), but also on car drivers (34). Compared to previous studies, the fact that the cognitive tests from Witty SEM correlated with performance in climbing is an argument for applying this kind of evaluation to climbers. Furthermore, it argues that the Witty SEM is an effective method for predicting performance in climbing. The fact that cognitive agility and visual memory were positively associated with performance in climbing argues that these cognitive skills should be developed in climbing training. The practical application of the present study was defining a specific protocol for evaluating climbers with Witty SEM.

It has been generally accepted the link between sports performance and motor and physical abilities in addition to cognitive and perceptual skills (43). Several research from motor expertise domains suggested that climbers develop advantageous perceptual and cognitive skills as a function of their sports expertise (6). The importance of cognition in climbing has previously been supported by various studies. Not only the perception of a single move from one hold to another is important, but also the ability to perceive how to link the moves together into an effective motor sequence prior to the climb (44). This requires climbers to integrate judgment skills with cognitive processes that link those motor actions together into a motor sequence. Furthermore, it is important that the climber remembers what sequence they performed in the past attempts and succeeded so that they can adjust the future try accordingly. In addition, a climber has to analyze this new motor sequence to previous motor sequences performed on previous routes, so they need a good motor memory. It is crucial that the climber does his plan for ascending before entering the climb because doing the plan while maintaining grip, balance, and body position will lead to additional attentional demands (45). Before a climber starts a route, he has to plan the actions that will lead him to success (route finding, planning, and problem-solving) (45). The athlete has to perceive the hold's reachability and characteristics from various positions (42) and has to decide if the hold can be grasped with the hand or used for foot support (37). Planning, problem-solving, and remembering routes (with working memory and motor memory) are important cognitive skills in climbing (46).

Lastly, because we analyzed the cognitive function of the climbers, we had to take into account the influence of education level. We saw that the predictive value of visual memory errors on the on-sight performance depended on the education level. The grade of the regression slope is the steepest for middle scholars and the least steep for University students. This suggests that for climbers with lower education levels, poor performance on motor-cognitive tests will more strongly predict lower on-sight performance. This result is in line with previous studies that analyzed the relationship between physical activities and cognition depending on age (47).

CONCLUSION

Our study analyzed the influence that some cognitive variables (reactivity and spatial skills using Cognitrom assessment system) and some motor-cognitive skills (cognitive agility, visual processing speed, and visual memory using Witty SEM technology) have on performance in youth advanced climbers. We demonstrated that cognitive skills measured in a motor task can predict better climbing performance than cognitive skills in general. Evaluating cognition in a motor task is more effective in predicting climbing performance than evaluating cognition in laboratory conditions.

On the other hand, the practical application of our study was presenting a specific protocol for predicting climbing performance with Witty SEM. The red A test and eye for detail test were suitable for predicting performance in climbing. The hawk eye test was not specific for evaluating performance in climbing, probably due to its lack of applicability.

On the other hand, we tested Cognitrom assessment system that evaluates the cognition skills of elite climbers and demonstrated that reactivity was not associated with climbing performance.

Finally, we explained the influence that the school background has on the relationship between visual memory and climbing performance. It appeared that high school climbers would have the best improvement when training cognition in motor tasks.

Our study had several strengths. The main strength comes from the novelty of the study, more exactly widening the area of use of Witty SEM technology and Cognitrom Assessment system. We formulated a protocol for evaluating climbers in accordance with their climbing performance and this is the practical application of the study. On the other hand, another strength of the study is the research group, evaluating the best youth climbers from Romania, a population that was hard to gather from different cities around the country. In addition, we evaluated some cognitive and motor-cognitive skills a climber needs, abilities that are often omitted in athlete preparation in comparison with physical, technical, or psychological skills.

The study had some limitations. Firstly, our cross-sectional design cannot infer a causal relationship between variables. Secondly, the cognitive variables were measured with a battery that analyzed reactivity and spatial skills in general. Future studies and assessment tools should be developed to evaluate climbing-specific cognition. Another limitation comes from the fact that the best performance of the climbers was recorded from their subjective history and on different routes (as their personal best). Future research should analyze the cognitive factors that influence competitive performance, where all the climbers from the research group are in rivalry with the others and compete on the same route/routes. Lastly, we analyzed only climbers specialized in lead climbing and bouldering, at the competitional level. Future research should analyze the cognition of speed climbers, traditional climbers, or recreational climbers.

APPLICABLE REMARKS

- Evaluating cognitive skills in a motor task is more effective in predicting climbing performance than evaluating cognitive skills in laboratory conditions.
- Cognitrom assessment system and the Witty SEM system are two novel technological methods that evaluate cognition in climbing and can predict climbing on-sight and red-point performance.
- Cognitive agility and visual memory are key factors for performance in climbing.
- Visual processing speed and reactivity are not predictors of climbing performance in lead climbing or bouldering.
- A high level of image generation can lead to overstimulation in the climber's mind and can lead to falling.
- School background influences the relationship between cognition and climbing performance, a higher education protects the climber from the negative effect of cognitive errors on climbing performance.
- The present research evaluated all elite youth climbers from Romania and highlighted the importance of cognitive training in supporting performance.

ACKNOWLEDGMENTS

The research was conducted under the auspices of the Doctorate School of the National University of Physical Education and Sports from Bucharest and in the Laboratory for Interdisciplinary Research Dr. Alexandru Partheniu.

AUTHORS' CONTRIBUTIONS

Study concept and design: Antonia Ioana Vasile, Monica Stănescu. Acquisition of data: Antonia Ioana Vasile, Teodora Velea. Analysis and interpretation of data: Antonia Ioana Vasile. Drafting the manuscript: Antonia Ioana Vasile, Kyle Chesler, Teodora Velea. Critical revision of the manuscript for important intellectual content: Antonia Ioana Vasile, Kyle Chesler, Monica Stănescu. Statistical analysis: Antonia Ioana Vasile. Administrative, technical, and material support: Antonia Ioana Vasile, Monica Stănescu. Study supervision: Doina Croitoru, Monica Stănescu.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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