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COMPARISON OF UPPER AND LOWER BODY DYNAMIC BALANCE BETWEEN SPORT CLIMBERS AND NON-CLIMBERS

PRIMERJAVA DINAMIČNEGA RAVNOTEŽJA ZGORNJEGA IN SPODNJEGA DELA TELESA MED ŠPORTNIMI PLEZALCI IN NEPLEZALCI

ABSTRACT

One of the factors for success in sports climbing, now receiving increased attention in scientific literature, is balance. Therefore, we conducted a research experiment to compare the dynamic balance between climbers and non-climbers through Y-balance test (YBT). A research experiment was carried out involving 50 participants, including 25 sport climbers, and 25 individuals active in various other sports. Subjects completed a sports participation questionnaire and performed three tests: YBT for lower and upper quarter, as well as the Closed Kinetic Chain Upper Extremity Stability test (CKCUEST). The analysis showed significantly higher results in sport climbers in the Y Balance Test on both lower (p = 0.001-0.017) and upper quarter (p = 0.001-0.002), as well as in CKCUEST (p=0.014–0.023). No significant differences were found for individual's dominant side or gender in YBT. Composite scores of both YBT tests were moderately correlated with normalized CKCUEST score (r = 0.41-0.57; p = 0.001 – 0.003). Sport climbers who regularly engage in strengthening exercises achieved rather better outcomes in specific combinations and directions. Balance may be one of the relevant factors for success in sport climbing and further research is needed in this area.

Keywords: sport climbing, dynamic balance, Y-test, balance assessment

IZVLEČEK

Eden od dejavnikov za uspeh v športnem plezanju, ki šele zdaj prejema vse več pozornosti v znanstveni literaturi, je ravnotežje. Izvedli smo raziskavo za primerjavo dinamičnega ravnotežja med plezalci in neplezalci s pomočjo Y-ravnotežnega testa (YBT). Raziskava je vključevala 50 preiskovancev, med njimi 25 športnih plezalcev in 25 posameznikov, ki so aktivni v različnih drugih športih. Preiskovanci so izpolnili vprašalnik o športni udeležbi in izvedli tri teste: YBT za spodnji in zgornji kvadrant ter test zaprte kinetične verige za stabilnost zgornjih okončin (angl. CKCUEST). Analiza je pokazala boljše rezultate pri športnih plezalcih v Y-ravnotežnem testu za spodnji (p = 0,001-0,017) in zgornji kvadrant (p = 0,001-0,002) ter v CKCUEST (p = 0,014–0,023). Pri YBT niso bile ugotovljene pomembne razlike glede na dominantno stran ali spol posameznika. Sestavljeni rezultati obeh YBT testov so bili zmerno korelirani z normaliziranim CKCUEST rezultatom (r = 0,41-0,57; p = 0,001 – 0,003). Športni plezalci, ki redno izvajajo krepilne vaje, so dosegli nekoliko boljše rezultate v specifičnih kombinacijah in smereh. Ravnotežje je lahko eden od pomembnih dejavnikov za uspeh v športnem plezanju, zato predlagamo nadaljnje raziskave na tem področju.

Ključne besede: športno plezanje, dinamično ravnotežje, Y-test, ocena ravnotežja

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INTRODUCTION

Sport climbing is a complex activity, distinct from other land movements due to the significant role of the upper limbs and its predominantly vertical movement, which involves elevating the climber's center of mass (Quaine and Martin 1999). To maintain balance, climbers must learn new movement strategies, ensure coordination of all body parts involved in vertical movement, and develop the ability to swiftly execute sequential movements (Di Paola, Caltagirone, and Petrosini 2013). Success in sport climbing hinges on coordinating several factors, with balance increasingly recognized as important (Aykora 2019; Ignjatović, Stanković, and Pavlović 2016; MacKenzie et al. 2020). This importance is echoed in discussions among elite sport climbers (Watts, Martin, and Durtschi 1993). Despite this, balance in sport climbing remains relatively unexplored, as scientific research has not kept pace with the sport's growing popularity. Balance is fundamentally defined as the ability to maintain the body's center of gravity above the base of support (Horak 1997). In the context of sport climbing, this concept takes on a broader meaning due to the vertical nature of the activity. Here, balance can be described as a state where the sum of all forces acting on the climber equals zero. This occurs either when these forces inherently neutralize each other, or when the climber effectively opposes them, such as counteracting gravity, resulting in a net force of zero (Ragnarsdóttir 1996).

Experienced sport climbers tend to move more dynamically during ascents, with their center of mass oscillating more compared to their less experienced counterparts (Russell, Zirker, and Blemker 2012; Zampagni, Brigadoi, and Ivanenko 2010). In contrast, less skilled climbers exhibit more rigid movements and demonstrate less fluid weight transfers. Conversely, more skilled climbers typically transfer most of their weight onto one leg before moving the other leg to the next hold (Zampagni et al. 2010). This technique helps experienced climbers minimize fatigue and maximize performance (Russell et al. 2012). Given these observations, it can be inferred that sport climbers, in addition to having sufficient muscular capacity and proprioception, also require adequate dynamic balance for efficient, technically refined, and fluid movement. However, the literature on field assessment of balance among sport climbers is limited, with methodologies and tests in previous studies showing considerable heterogeneity. Research has found that sport climbers demonstrate better postural balance compared to sedentary individuals when tested on a force plate in various conditions, including quiet bipedal stance with open and closed eyes, and in a visual conflict condition (Aras et al. 2018). Additionally, elementary school children have shown improved balance in the one-legged standing flamingo test after two months of daily sport climbing activity (Aykora 2019).

Moreover, male climbers are reported to have better balance in this test compared to their female counterparts (Stanković, Dicle, and Raković 2021).

Balance, as measured by the Star Excursion Balance Test, is thought to correlate with climbing proficiency (Arazi et al. 2018). However, static balance in a quiet bipedal stance seems consistent across climbers of varying skill levels, while dynamic balance, as determined by limits of stability assessments, tends to be superior in higher-level climbers (Akşit and Çırık 2017). Although the Y Balance Test – Lower Quarter (YBT-LQ), similar to the Star Excursion Balance Test, has been employed in some studies involving sport climbers (Nichols et al. 2018), the nature of sport climbing suggests that the Y Balance Test – Upper Quarter (YBT-UQ) might be more relevant. To our knowledge, this application has not yet been scientifically explored. In addition, only one study has focused on the comparison of balance among climbers participating in different disciplines of sport climbing and found that while balance does not significantly affect performance in lead or speed climbing, it plays an important role in bouldering (Ignjatović et al. 2016).

In this study, we aimed to compare dynamic balance between sport climbers and non-climbers using the YBT-LQ and YBT-UQ. As a secondary aim, we also compared the difference between the groups in terms of another upper limb stability test - Closed Kinetic Chain Upper Extremity Test (CKCUEST) test (Goldbeck and Davies 2000) and the association between YBT and CKCUEST. Our focus is on understanding how climbing, particularly bouldering, influences dynamic balance abilities, and whether these skills differ significantly from those engaged in other sports. The results of this research could provide new insights into the physical demands of sport climbing and contribute to the development of targeted training programs for climbers.

METHODS

Participants

The study included 50 healthy, adult volunteers, divided equally into a climbing group, primarily engaged in bouldering, and a control group involved in sports other than climbing. Eligible participants had no upper or lower limb, or spinal injuries or surgeries in the past six months. Exclusion criteria encompassed recent concussions, any condition impeding work or sports in the past six months, limb amputations, vestibular disorders, ongoing pregnancy, current illnesses or injuries impacting physical or balance performance, and ongoing treatment for inner ear, sinus, or respiratory infections. Participants were briefed about the study,

consented voluntarily, and were free to withdraw at any point. They signed a consent form before testing and received their individual results afterward. The study was approved by the National Medical Ethics Committee (No. 0120-690/2017-8).

Measurements procedures

This was a cross-sectional study. The testing took place in a controlled laboratory environment in June and July 2023. Participants were tested once on each of the tests: YBT-LQ, YBT-UQ, and CKCUEST. To minimize potential order effects, the sequence of the tests was assigned using a quasi-randomized approach, ensuring a balanced distribution of test orders among participants. All tests were conducted by a team of trained researchers with expertise in sports science and physical therapy. All subjects completed a questionnaire consisting of three sections: baseline data, sport participation and strength training. Climbers additionally answered questions on the form of sport climbing they are involved in and the highest rated boulder they successfully climbed. In the third section, all subjects reported on whether they regularly perform any strength exercises, along with frequency and duration. Afterwards, we measured the length of the right upper and right lower limb to the nearest 0.5 cm using a tape measure. The lower limb was measured in a supine position from the most prominent part of the spine iliaca anterior superior to the most prominent part of the medial malleolus. The upper limb was measured in the standing position with the arm in 90° shoulder abduction, from the C7 spinous process to the tip of the longest finger. The results for both YBT-LQ and YBT-UQ were first recorded in absolute length, measured to the nearest 1 cm. For further analysis, the average of the three absolute reach lengths was used for each direction. To standardize the results, the reach distances were expressed as % of the limb length.

All of these tests were performed barefoot. For the YBT-LQ test, we followed the protocol of Plisky et al. (Plisky et al. 2009). The participant performed reaches in the anterior, posterolateral and posteromedial direction while maintaining a unilateral stance on a standardized device. Movement of the trunk and arms was allowed and a 30-s rest period was provided between measurements. The YBT-UQ was administered in accordance with the protocol of Gorman et al. (Gorman et al. 2012). The participants reached medial, superolateral and inferolateral direction while maintain a push up position. Pelvic movement was permitted and a rest interval of 60 seconds was provided between repetitions. To perform CKCUEST, we followed the protocol of Goldbeck and Davies (Goldbeck and Davies 2000). Participants alternately raised one arm and swung it over their standing arm and backwards while maintaining a push up

position with hands 91.5 cm apart, all within a 15-second timeframe. The starting position was consistent for both male and female participants. The recorded test result was determined as the average count of absolute number of touches across three repetitions. To standardize the data, the relative number of touches was calculated by diving the results with body height. The third outcome was power, calculated by multiplying the absolute number of touches with 68 % of body mass and dividing by 15.

Data analysis

The data were statistically analyzed using IBM SPSS Statistical software, version 26 (IBM Corporation, US). Descriptive statistics were calculated and presented as the mean and standard deviation. The normality of the data distribution was assessed through the Shapiro-Wilk test and visual assessment of histograms. The relative reliability was evaluated using the intraclass correlation coefficient (ICC), with the typical error expressed as a percentage of the mean value. ICC values below 0.5 were considered indicative of poor reliability, values ranging from 0.5 to 0.75 indicated moderate reliability, values between 0.75 and 0.9 signified good reliability, and values exceeding 0.90 were indicative of excellent reliability (Koo and Li 2016). Acceptable reliability was defined as a typical error below 10% (Hopkins 2000). The results of all three field tests performed (YBT-LQ, YBT-UQ and CKCUEST) were analyzed using a two-way analysis of variance, with one factor representing gender (male, female) and the other factor representing group (climbers, control group). This analysis was used to examine possible differences in scores between gender, between group and possible interaction between the two factors (gender and group). Effect size was quantified using partial $\eta 2$, with values interpreted as follows: insignificant (<0.01), small (0.01–0.06), medium (0.06–0.14), and large (>0.14) (Cohen 1988). In addition, when statistically significant differences were found, we performed a comparison by sex for each group separately and a comparison between the two groups for each sex separately. These comparisons were carried out using t-test for independent samples with Bonferroni correction. The effect size was expressed using Cohen's d, according to which the effect size is interpreted as non-significant (<0.2), small (0.2–0.5), medium (0.5–0.8) and large (>0.8) (Cohen, 1988). Furthermore, we utilized the independent samples t-test to explore differences between amateur and recreational climbers as well as possible differences between those climbers who regularly perform resistance training and those who do not. Pearson's correlation coefficient was employed to analyze associations between the results of all three field tests (YBT-LQ, YBT-UQ, and CKCUEST). These associations were classified as negligible (<0.1), weak (0.1–0.4), moderate (0.4–0.7), strong (0.7–0.9), or very strong (>0.9)

(Akoglu 2018). Considering the small sample size, we added 95% confidence intervals (CI) To address the confidence in the correlation coefficients. To assess the relationships between the results of the field tests and an individual's climbing level or years of climbing training, Spearman's rank correlation coefficient was employed. The interpretation of these associations followed the same criteria as for Pearson's correlation coefficient. Statistically significant differences were accepted at a confidence level of $\alpha < 0.05$.

RESULTS

Subjects

The study involved 50 subjects, 25 sport climbers and 25 controls. Mean age, body mass and height are shown in Table 1.

Table 1. Participant characteristics.

Group	Gender	N	Age (years)	Body mass (kg)	Height (cm)
			$\bar{x}$ ± SD [range]		
Climber	M	16	31,9 ± 9,4 [22–59]	75,6 ± 6,5 [63–90]	178,8 ± 4,7 [173–190]
	F	9	28,1 ± 7,5 [19–41]	61,2 ± 10,2 [45–78]	167,3 ± 5,7 [158–178]
Control	M	14	27,1 ± 8,8 [20–57]	78,8 ± 12,5 [58–110]	182,2 ± 6,6 [166–193]
	F	11	27,3 ± 9,3 [22–55]	60,1 ± 5,3 [52–68]	168,3 ± 4,8 [160–176]

Notes. N – number of subjects, SD – standard deviation

In the climbing group, the majority of the 23 subjects (92%) are mainly involved in bouldering, while two subjects are mainly involved in lead climbing. None of them pursue sport climbing professionally, 6 are amateurs (individuals who undergo regular and systematic training, participate in competitions, but this is not their primary occupation), 18 are regular recreational climbers (engaging in the sport multiple times a week) and 1 subject is an occasional sport climber. Their climbing frequency ranges from 1 to 2 times a week to 5 times a week, with an average of 2 to 3 times per week, and their climbing experience spans from 2 to 21 years, averaging 9 years. In terms of the most difficult boulder problem climbed, the subjects fall into the range of grades 6a to 8a on Fontainebleau scale. Additionally, the majority of these subjects participate in other sports alongside sport climbing, with cycling, hiking, and winter sports being the most popular choices.

In the control group, the majority of 21 (84%) subjects are actively involved in sports, while 4 subjects are physically inactive. These individuals participate in a diverse range of sports, with cycling, hiking, fitness, group exercise, surfing, volleyball and yoga among others. Their

engagement in these sports varies, with experience spanning from six months to 45 years (averaging 5.1 years) and weekly participation ranging from once to seven times (averaging 2 to 3 times). Specifically, 13 subjects engage in sports on a regular recreational basis, 8 do so occasionally, and 4 do not participate in sports. None of the individuals in the control group are engaged in sports at an amateur or professional level.

Reliability

Table 2 shows reliability analysis. Relative reliability for the YBT-LQ was good *(ICC = 0.80–0.90)*, while for the YBT-UQ it was excellent *(ICC = 0.90–0.95)*. Absolute reliability was acceptable for all directions for both tests, with typical errors below the 10% limit for both the lower *(TE = 3.3–6.4%)* and upper *(TE = 2.7–4.5%)* extremities. The CKCUEST test also showed excellent reliability *(ICC = 0.95; TE = 4.3%)*.

Table 2. Reliability analysis.

		Relative reliability			Absolute reliability		
Test	**Direction/variable**	**ICC**	**95 % CI**		**TE**	**95 % CI**	
YBT-LQ, non-dominant	Anterior	0.80	0.70	0.88	6.46	5.59	7.70
	Posteromedial	0.90	0.84	0.94	2.80	2.42	3.34
	Posterolateral	0.85	0.76	0.91	3.90	3.37	4.65
YBT-LQ, dominant	Anterior	0.84	0.75	0.90	5.72	4.95	6.82
	Posteromedial	0.86	0.78	0.91	3.32	2.87	3.96
	Posterolateral	0.85	0.77	0.91	3.77	3.26	4.49
YBT-UQ, non-dominant	Medial	0.94	0.91	0.97	2.81	2.43	3.35
	Superolateral	0.95	0.92	0.97	4.25	3.68	5.07
	Inferolateral	0.92	0.88	0.95	3.84	3.33	4.58
YBT-UQ, dominant	Medial	0.94	0.90	0.96	2.76	2.39	3.30
	Superolateral	0.93	0.89	0.96	4.54	3.93	5.42
	Inferolateral	0.90	0.84	0.94	4.03	3.49	4.81
CKCUEST	Number of touches	0.95	0.91	0.97	4.30	3.72	5.12

Notes. ICC – intraclass correlation coefficient, TE – typical error, CI – confidence interval

Differences based on dominant side

The paired t-test showed no statistically significant differences in the mean value between the dominant and non-dominant side for both groups, for both YBT-LQ and YBT-UQ (t(24) = -1.609–1.457; p = 0.121–0.927).

Differences based on group and gender

For the YBT-LQ test, a two-way ANOVA showed a statistically significant, moderate to large effect of group for all three reach directions and the composite score, on both the dominant and

non-dominant leg *(F = 4.88–12.34; p = 0.001–0.032; η2 = 0.09–0.21)*. There was no effect of gender for either direction *(p = 0.075–0.802)*, nor was there an interaction between gender and group *(p = 0.054–0.938)*. Accordingly, an independent-samples t-test detected no significant differences between males and females *(p = 0.073–0.922)*. Comparison between the climbers and the control group by t-test showed statistically significantly better results for the climbers for all directions and the composite score on both legs *(p = 0.001–0.017)* with a moderate effect size *(d = 0.50–0.78)*. The results of the comparison between the two groups for the dominant leg are presented in Figure 1A (results for non-dominant side are similar and are omitted for clarity).

For the YBT-UQ test, a two-way ANOVA on both arms showed a statistically significant, large group effect for lateral reach, inferolateral reach, and the composite score *(F = 9.26–16.01; p = 0.001–0.004; η^2 = 0.17–0.25)*. However, for superolateral reach, the group effect was not statistically significant on either the dominant *(p = 0.115)* or non-dominant side *(p = 0.247)*. For either direction, there was no main effect of gender *(p = 0.076–0.792)*, nor was there a gender-by-group interaction *(p = 0.124–0.938)*. An independent samples t-test also indicated no significant gender differences *(p = 0.061–0.896)*. When comparing sport climbers with the control group using a t-test, results aligned with the ANOVA findings, showing statistically significant superior performance by climbers in lateral reach, inferolateral reach, and the composite score *(p = 0.001–0.002)*, with moderate to high effect sizes *(d = 0.64–0.81)*. The results for the dominant arm are presented in Figure 1B.

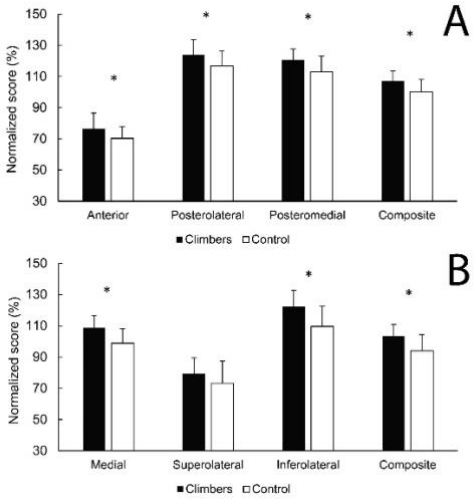

Figure 1. Differences between climbers and control group in YBT-LQ (A) and YBT-UQ (B) across directions. *Denotes statistically significant difference between climbers and the control group.

Analysis of the CKCUEST results showed a high statistically significant effect of gender on absolute score *($F = 17.2$; $p < 0.001$; $\eta^2 = 0.27$)* and power score *($F = 45.9$; $p < 0.001$; $\eta^2 = 0.50$)*. Conversely, the effect of gender on the normalized score was also statistically significant but moderate *($F = 6.4$; $p < 0.015$; $\eta^2 = 0.12$)*. There was also a moderate, statistically significant effect of group for both absolute and normalized scores *($F = 5.53–6.55$; $p = 0.014–0.023$; $\eta^2 = 0.11–0.12$)*, but this effect was not significant for power score *($p = 0.147$)*. There was no interaction between gender and group for any of the variables in the CKCUEST test *($p = 0.485–0.931$)*. The results are shown in Table 3.

Table 3. Results of CKCUEST by group and gender.

	Climbing group		**Control group**	
	Male	**Female**	**Male**	**Female**
Variable		**$\bar{x}$ ± SD**		
Absolute result	27.9 ± 3.5	22.8 ± 3.23	24.7 ± 4.1	21.0 ± 3.2
Normalized result	15.6 ± 1.9	13.6 ± 1.64	13.6 ± 2.4	12.5 ± 2.0
Power score	95.5 ± 13.0	64.2 ± 16.5	89.0 ± 22.0	56.9 ± 7.2

Notes. SD – standard deviation

Correlations between tests

In the analyses of correlations between tests, we limited our analysis to the composite scores of both YBT tests for the dominant side and the normalized score and power output of the CKCUEST to reduce the number of correlation coefficients and thereby minimize the risk of Type I statistical error. There was a moderate-to-high and statistically significant positive correlation between the composite scores of the YBT for the lower and upper quarter *($r = 0.64$; 95% CI = 0.44 – 0.78; $p < 0.001$)*. The composite YBT-UQ score was statistically significant positively correlated with the normalized CKCUEST score *($r = 0.57$; 95%CI = 0.35-0.73; $p < 0.001$)*, and had trivial-to-moderate and statistically significant correlation with the power score *($r = 0.31$; 95%CI = 0.03 – 0.54; $p = 0.027$)*. The YBT-LQ composite score was also in trivial-to-moderate statistically significantly correlation with the normalized CKCUEST score *($r = 0.41$; 95% CI = 0.15 – 0.62; $p = 0.003$)*, but not with power output *($p = 0.111$)*.

Correlations between results and level of climbing

No YBT or CKCUEST scores were associated with years of training *(all $r < 0.25$; all $p > 0.225$)*. However, a positive trivial-to-moderate correlation was observed between an individual's climbing level and the total score of the YBT-LQ for both legs *($r = 0.39$; 95% CI*

= 0.01 – 0.68; p = 0.049 for both legs). No other correlations were found between climbing level and YBT-LQ, YBT-UQ and CKCUEST scores.

In addition, we used an independent samples t-test to test for differences between amateur and recreational climbers. Amateur climbers had better YBT-UQ composite scores on the dominant arm *(107.6 ± 3.3%)* compared to recreational climbers *(102.1 ± 7.9%)*, with this difference being statistically significant *(p = 0.023; d = 0.65)*. The same was observed on the non-dominant arm, amateur climbers *(107.1 ± 3.4%)* had better results compared to recreational climbers *(101.5 ± 9.5%)*, the difference was statistically significant *(p = 0.042; d = 0.55)*. Additionally, differences occurred in inferolateral reach, but only for the dominant arm *(amateur: 107.6 ± 3.3%; recreational 102.1 ± 7.9%; p = 0.023; d = 0.65)*.

Furthermore, independent samples t-tests were used to test whether there were differences in the YBT-LQ, YBT-UQ and CKCUEST test scores among climbers who regularly engaged in strengthening exercises *(n = 11)* compared to those who did not *(n = 14)*. Those who performed the strengthening exercises had a better score than those who did not in certain combinations and directions. Specifically in posterolateral direction with the non-dominant leg *(123.9 ± 6.1% vs. 118.1 ± 6.9%; p = 0.037; d = 0.64)*, in medial direction with the dominant arm *(112.9 ± 6.9% vs. 105.4 ± 6.8%; p = 0.012; d = 0.77)*, and a better YBT-UQ composite score for the dominant arm *(106.8 ± 6.3% vs. 100.7 ± 7.3%; p = 0.014; d = 0.64)*.

DISCUSSION

The primary goal of this study was to examine the differences in dynamic balance between sport climbers and non-climbers. Our findings revealed a consistent advantage for sport climbers in all directions and limbs on the YBT-LQ, in all directions and limbs except superolateral on the YBT-UQ, and in both absolute and normalized scores on the CKCUEST. The analysis did not indicate a significant interaction between gender and group for any of the three tests. While no significant gender differences were observed in YBT-LQ and YBT-UQ, a moderate gender effect emerged in the CKCUEST. In contrast, significant group differences were noted across all tests, favoring the climbing group. Furthermore, no correlation was found between the test scores and the number of years of sport climbing experience. The climbing level showed a positive trivial-to-moderate correlation with their total score on the YBT-LQ, but not on the YBT-UQ.

Our study corroborates the primary hypothesis, confirming superior scores in both YBT tests among climbers. This supports existing research highlighting the significance of balance in sport climbing (Akşit and Çırık 2017; Aras et al. 2018; Aykora 2019; Ignjatović et al. 2016; Nichols et al. 2018; Stanković et al. 2021). Previous research indicates that sport climbers possess better balance compared to sedentary adults (Aras et al. 2018). In our study, despite similar weekly sport participation rates between the climbing and control groups, sport climbers consistently demonstrated superior dynamic balance. This suggests the high validity of these tests for assessing balance in climbers. From our observation during the measurements, it seems that the sport climbers' approach to the tests reflected their problem-solving strategies in bouldering, involving deliberate strategy application and diverse method exploration for optimal results. These tests necessitate continuous anticipation, movement planning, ongoing movement correction, and balance control—processes integral to many sports, including sport climbing, and regulated by the cerebellum. Long-term training is known to induce structural brain changes, such as increased cerebellar volume, also observed in climbers (Di Paola et al. 2013). However, it remains unclear whether these structural brain differences are a result of or a precursor to functional differences, leaving open the question of whether a 'climber's brain' leads to superior climbing abilities or is a consequence of extensive climbing experience (Di Paola et al. 2013), warranting further investigation. In the YBT-LQ, stronger individuals often used a deep squat on one leg to optimize their anterior reach, whereas more flexible individuals rotated their pelvis at the lowest position to extend reach, aligning with findings that flexibility can compensate for muscular strength to some extent (Nichols et al. 2018). Sport climbers in our study frequently demonstrated such adjustments, suggesting their excellent control in extreme positions and ability to effectively utilize strengths to compensate for weaknesses.

Further analysis explored the relationship between test results and sport participation levels among sport climbers. No correlation was evident between test scores and years of sport climbing experience. However, previous research has shown balance improvements in children after two months of daily sport climbing (Aykora 2019). The lack of correlation in our adult participants, who had an average of 9 years of climbing experience, might be attributed to the plateauing of motor skill development beyond a certain point. The climbing level, as determined by the highest-rated bouldering problem climbed by a participant, correlated positively with the YBT-LQ score ($r = 0.39$). This may be due to the nature of more challenging boulders, which require precise footwork and extended leg movements, akin to the YBT-LQ. Our findings align with other studies linking climbing level and balance performance (Akşit and Çırık 2017; Arazi

et al. 2018). However, a wide 95%CI (0.01 – 0.68) for this correlation must be acknowledged and further studies with larger samples are need to describe this relationship (or lack thereof) more precisely. In contrast, no correlation was found between climbing level and YBT-UQ score, possibly due to the differing roles of upper limbs in sport climbing and in the YBT-UQ. Additionally, as sport climbing typically involves vertical movements, while the YBT tests occur in a horizontal plane, training in one plane may not directly enhance performance in the other due to distinct challenges. Balance training research suggests that improvements are often task-specific and may not transfer to untrained tasks (Kümmel et al. 2016), likely due to specific neural adaptations from training.

We also investigated differences between amateur and recreational sport climbers, with amateurs defined as those engaging in regular, systematic training and competitions, and recreational climbers as those who climb several times a week. Amateur climbers scored better on both arms in the YBT-UQ. Differences between climbers who regularly engage in strengthening exercises and those who do not were also examined. Climbers performing strengthening exercises tended to achieve better results in specific YBT-LQ and YBT-UQ combinations. Prior research primarily focused on static balance in different climbing disciplines, with significant balance effects noted only in bouldering (Ignjatović et al. 2016). Our study, primarily involving boulder climbers, employed dynamic instead of static balance tests, reflecting the dynamic nature of sport climbing. However, most of our findings relate specifically to boulder climbers, suggesting the need for further investigation into dynamic balance across different climbing disciplines.

The YBT-UQ and CKCUEST both primarily assess upper body and trunk muscle performance in a closed kinetic chain, so a correlation between the two is expected. We found a moderate positive correlation ($r = 0.57$) with the normalized CKCUEST score and a small positive correlation ($r = 0.31$) with power output, consistent with other studies (Westrick et al. 2012).The stronger association between the YBT-UQ and normalized CKCUEST score is logical, as the normalized score indicates upper body stability and endurance, traits likely to result in better YBT-UQ performance. However, the CKCUEST's power output, which measures explosiveness and strength, showed a less direct relation to the stability and neuromuscular control assessed in the YBT-UQ. As these tests evaluate different but related constructs, they can effectively complement each other in assessing an athlete's abilities.

The YBT-LQ and YBT-UQ showed a moderate, statistically significant correlation, indicating that abilities in one body segment often reflect in another. A moderate correlation between the YBT-LQ and normalized CKCUEST score suggests that overall fitness may influence performance across different tests, despite them assessing various body parts and muscle groups. No correlation was observed between the YBT-LQ and CKCUEST power output, in line with the distinct abilities each test evaluates. Again, the 95% confidence intervals were relatively wide and further investigation with larger samples is critically needed.

CONCLUSION

Our study aimed to compare dynamic balance in sport climbers with a non-climbing control group. Findings revealed superior performance in sport climbers on the YBT-LQ, YBT-UQ, and CKCUEST tests, indicating their enhanced dynamic balance. Despite no observed differences in Y balance tests between dominant and non-dominant sides, challenges on the non-dominant limb warrant further exploration. A significant advantage in dynamic balance was consistently found for sport climbers, noteworthy since both groups trained similarly, about 2-3 times per week. Differences were more pronounced between higher and lower skilled climbers; those in regular, systematic training and competitions outperformed recreational climbers, especially in certain YBT-UQ outcomes. Climbers engaging in strength training also showed improved results in specific YBT test aspects, suggesting the potential for targeted training programs. The study primarily focused on boulderers, highlighting a need for future research on dynamic balance across various sport climbing disciplines.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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