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EVALUATION OF BALANCE AND MUSCLE STRENGTH OF UPPER AND LOWER LIMBS IN ROCK CLIMBERS

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Abstract

Introduction. The purpose of this study was to evaluate the effects of bouldering on upper and lower limb muscle strength and body balance. ***Material and Methods.*** The study group consisted of 22 climbers (aged 27.23 ± 4.81) with at least 2 years of bouldering experience, while the control group consisted of 20 men (aged 23.10 ± 5.28) not practicing rock climbing. The study received approval from the local bioethical commission in Poland. Static and dynamic stabilographic parameters were measured with eyes open (EO) and closed (EC) on the Biodex Balance System SD USA (BBS) platform. Subsequently, the maximum muscle torques of the elbow, hip, knee and ankle joints were measured in isometric conditions. Hand-grip strength (HGS) with and without the thumb was assessed using a handheld dynamometer. ***Results.*** Climbers achieved significantly higher values of HGS with the thumb of both hands ($p < 0.005$), foot extensors strength (FES) in both limbs ($p < 0.05$) and left hip extensors (HES L) ($p < 0.05$). They also achieved significantly lower values of all stabilographic parameters, indicating better balance compared to the control group ($p < 0.05$). An interaction of HES x SIDE across the groups was observed ($F(1,40) = 13.588$, $p < 0.001$ $\eta 2 = 0.254$). Moreover, there was a statistically significant negative correlation of ankle extensors strength with medial-lateral stability index (MLSI EC) (right: $r = -0.418$; left: $r = -0.331$) and fall risk index (FRI6-2) (right: $r = -0.520$; left: $r = -0.435$). ***Conclusions.*** Regular climbing training develops muscle strength, especially FES, HES, HGS, and improves balance. Climbing can be used for prevention of muscle weakness and equilibrium disorders.

Key words: climbing, body balance, muscle strength, bouldering

Introduction

As a sport, bouldering involves climbing a maximum 4-meter section (called a boulder problem) in several to a dozen moves, with crash-pad mats spread out at the base of the rock [1] protecting against the fall. Its popularity has grown significantly over the past few years. In 2014, there were about 7.7 million climbers in the United States alone, and new artificial sports facilities related to sport climbing are being built every year [2]. Rock climbing is a sport that requires a high level of physical fitness and technical skill [3, 4, 5]

The literature shows that the main contributing factors of a climber's high performance are the strength of the upper limbs and their climbing experience, which generates a high ability to navigate the wall [6]. Above-average performance in rock climbing is contributed to, among other things, maximum strength of the finger and hand flexors. Moreover, in climbers, the strength of hand and finger flexors plays an important role. It was significantly higher in athletes than in non-athletes [7]. Also, the relative strength of the ring finger had a significant impact on the climber's performance level [5].

The role of lower limbs in rock climbing is an issue sparsely described in the scientific literature. There are reports that analyze the effect of rock climbing on the strength and power generated by lower limbs before and after an adequate training period [8]. It was also previously observed that rock climbing training significantly improved performance in tests of lower limb strength in pedalling, vertical jump reach and number of squats performed [9]. However, the literature does not provide sufficient information on the role of lower limb strength in rock climbing, or the role of specific muscle groups.

Bouldering requires the athlete to have good postural stability, which refers to the ability to precisely control body posture since climbers often find themselves in unbalanced positions. Key parameters include the Center of Pressure (COP), which represents the projection of the body's center of gravity onto the support surface, and the Center of Mass (COM) of the climber, which must be maintained in the appropriate position to avoid imbalances. To achieve appropriate postural stability, climbers employ various strategies. These include controlling muscle tension, dynamic shifts of the COP, seeking points of optimal support for maximum stability, and optimizing body position with the placement of COM and COP to minimize force moments. These result in appropriate movements of the upper and lower limbs, trunk, head, and eyes [10]. The literature also frequently mentions typical biomechanical parameters such as muscle strength, range of motion, and reaction time as significant factors in maintaining body balance [11, 12, 13].

In bouldering, the movement of the Center of Mass (COM) is not projected onto the surface of support but rather is forced by the arrangement and distribution of climbing holds in the area. Among advanced climbers, significantly larger COM movement amplitudes during climbing moves were observed compared to the control group, which consisted of individuals with no climbing experience. Additionally, the COM was notably distant from the vertical climbing wall during movement initiation and in the resting position at the initial setup [14]. Moreover, limb loading on holds was asymmetric and significantly changed as advanced climbers ascended. This indicates a notably better COM distribution during climbing, which may correlate with enhanced postural control in static as well as dynamic conditions. The ability to better control the center of

gravity concerning the positioning of holds poses a significant challenge in relation to optimizing energy expenditure, stability, and safety during climbing.

Regarding the analysis of the aforementioned issues, this study aims to assess the muscle strength moments of both upper and lower limbs, as well as balance of climbers practicing the discipline of bouldering.

Material and Methods

The study was approved by the Senate Commission for Research Ethics at Józef Piłsudski University of Physical Education in Warsaw. The study group consisted of 22 male participants (aged 27.23 ± 4.81), who were rock climbers in the bouldering discipline. Inclusion criteria into the study group were as follows: males, aged 18-35, at least 2 years of experience in bouldering, and regular participation in climbing training sessions at least twice a week. Exclusion criteria included: any injuries sustained during the last 2 years (ankle, knee, hip, elbow and shoulder joints sprains and fractures, jammed fingers etc.) and irregular participation in climbing training. The control group consisted of 20 males, aged between 18-35 (aged 23.10 ± 5.28), who did not practice rock climbing, but engaged in various forms of physical activity and had no history of injuries within the last 2 years. Exclusion criteria in the control group included: injuries during the last 2 years and low levels of physical activity. All subjects provided written informed consent prior to data collection. Subsequently, all participants underwent a standardized warm-up under the supervision of the study conductor. After that, anthropometric measurements were performed. Climbers had significantly lower body mass ($p = 0.02$) and shorter waist circumference (WC) ($p = 0.04$) compared to the control group. The results are presented in table 1 (Tab. 1).

The measurement of hand-grip strength (HGS) was performed according to the guidelines of the American Society of Hand Therapists in a seated position, with the elbow joint flexed at 90° and the forearm and hand positioned in an intermediate position. Three measurements of HGS were taken for each hand, both with the use of the thumb (closed grip) and without. The peak muscle torques of the elbow, hip, knee, and foot flexors (plantar flexors) and extensors (dorsal flexors) groups were applied in accordance with the maximum voluntary contraction method on JBA Zbigniew Staniak® measurement stations [15, 16, 17, 18]. In all cases, right (R) and left (L) limbs were measured. The statistical analysis included the results with the highest values for all the strength measurements mentioned above. Normalized values of torque muscle moments per body weight of each subject were obtained. Furthermore, we analyzed the influence of limb side (left or right) on muscle strength values.

Postural stability was assessed using the Biodex Balance System (BBS) SD platform (USA). The Postural Stability Test was conducted while participants stayed on a stationary platform (static conditions). The following indicators were determined: Overall Stability Index (OSI) representing the general stability index, Anterior-Posterior Stability Index (APSI) for front-to-back sway in the sagittal plane, and Medial-Lateral Stability Index (MLSI) for side-to-side sway in the coronal plane with eyes open (EO) and closed (EC). Additionally, the Fall Risk Test was conducted on an unstable platform (dynamic conditions) with EO at levels ranging from 12 to 6, and from 6 to 2 (the platform is the most stable at level 12). From these measurements, the Fall Risk Index (FRI) values were determined. Each measurement consisted of 3 trials of 20 seconds each, with a 10-second break between trials.

Statistical analysis was performed using STATISTICA 13.0 (StatSoft). The Shapiro-Wilk test indicated the distribution of variables. The homogeneity of variance was assessed using Levene's test. T-test and Mann-Whitney U test were used to determine differences between groups. The ANOVA test for repeated measures and Bonferroni's post-hoc tests were performed to assess the interactions between variables. Spearman's rank correlation test was also performed. The level of significance was set at $p \leq 0.05$.



Figure 1. The measurement of the peak muscle torques for hip and foot extensors and flexors in isometric condition.

Table 1. Participants' anthropometric values

group	n	body mass [kg]	body height [cm]	BMI	WC [cm]	HC [cm]	WHR
climbers	22	71.57 ± 6.36	180.4 ± 6.1	22.03 ± 2.07	77.77 ± 5.39	93.2 ± 3.73	0.834 ± 0.04
control	20	82.49 ± 12.03	181.4 ± 6.9	24.91 ± 2.15	85.15 ± 7.65	100.7 ± 6.27	0.845 ± 0.04
total	42	76.72 ± 10.85	180.9 ± 6.4	23.40 ± 2.54	81.29 ± 7.48	96.8 ± 6.29	0.839 ± 0.04

Legend: BMI – Body Mass Index; WC – waist circumference; HC – hip circumference; WHR – Waist-Hip Ratio.

Results

Normalized values of torque muscle moments per body weight of each subject were performed. The statistical analysis revealed that climbers exhibited higher HGS with the thumb compared to the control group ($p < 0.001$). Additionally, individuals from the study group achieved significantly lower values of elbow extensors strength (EES) compared to the control group ($p < 0.05$). Detailed results of the above analysis are presented in table 2 (Tab. 2).

Furthermore, climbers achieved significantly higher values in the strength of both feet extensors (FES) and the left thigh extensors (HES L) compared to the control group ($p < 0.05$). They also achieved significantly lower values in the strength of the right thigh flexors (HFS R) compared to the control group ($p < 0.05$). Detailed results of the above analysis are presented in table 3 (Tab. 3).

There was no statistically significant interaction of FES x Side across the study and control group ($F(1,40) = 0.321$, $p = 0.574$, $\eta 2 = 0.008$). Statistically significant differences were observed in isometric FES between groups ($F(1,0) = 12.5$, $p = 0.001$, $\eta 2 = 0.238$). An interaction of HES x SIDE across the study and control group was observed ($F(1,40) = 13.588$, $p < 0.001$ $\eta 2 = 0.254$). Post-hoc tests showed significant differences between: HES L in the study group and HES R in the control group ($p = 0.017$), HES R and HES L in the study group ($p < 0.001$).

In addition, the values of stabilographic indices were subjected to statistical analysis. Climbers demonstrated significantly lower values in all static and dynamic indices compared to the study group ($p < 0.05$), which means they had better postural stability. Detailed results of the above analysis are presented in table 4 (Tab. 4).

It was also demonstrated that there was a statistically significant negative correlation between the strength of ankle joint extensors in both limbs and the results of balance parameters MLSI EC and FRI 6-2. Detailed results of the above analysis are presented in table 5 (Tab. 5).

Table 2. Normalized values of HGS and elbow muscle torque force moments for study and control groups

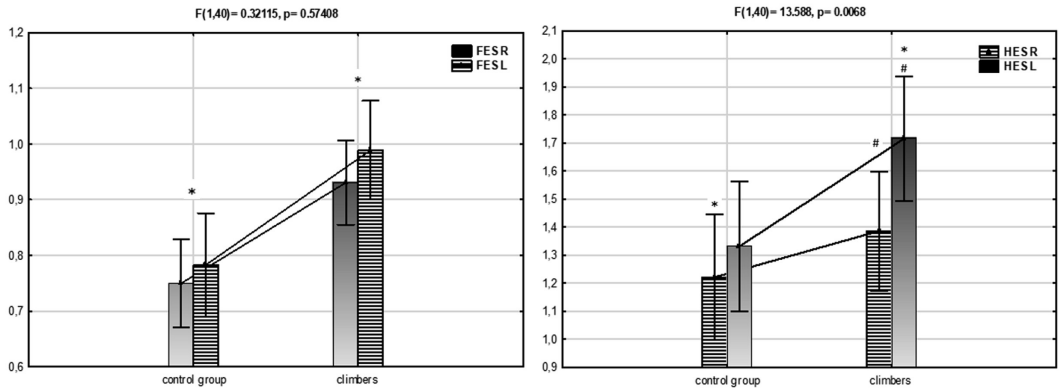
Parameters		Climbers			Control group			p
		Mean ± SD	Me	CI 95%	Mean ± SD	Me	CI 95%	
HGS [kg]	R	0.73 ± 0.13	0.67	0.67-0.79	0.60 ± 0.11	0.60	0.55-0.65	0.002*
	L	0.72 ± 0.15	0.72	0.66-0.79	0.60 ± 0.10	0.57	0.55-0.65	0.002*
HGS without thumb [kg]	R	0.58 ± 0.11	0.59	0.53-0.63	0.52 ± 0.10	0.55	0.47-0.57	0.064
	L	0.59 ± 0.14	0.57	0.53-0.66	0.54 ± 0.09	0.56	0.50-0.58	0.144
EES [N·m]	R	0.62 ± 0.09	0.62	0.58-0.66	0.70 ± 0.15	0.71	0.63-0.78	0.032*
	L	0.59 ± 0.11	0.59	0.54-0.64	0.70 ± 0.17	0.67	0.63-0.78	0.019*
EFS [N·m]	R	1.34 ± 0.20	1.38	1.25-1.43	1.31 ± 0.19	1.34	1.21-1.40	0.554
	L	1.31 ± 0.21	1.32	1.22-1.40	1.30 ± 0.21	1.36	1.20-1.40	0.904

Legend: HGS – handgrip strength; EES – elbow extensors strength; EFS – elbow flexors strength; R – right, L – left; CI – confidence interval; Me – median; * – $p \leq 0.05$.

Table 3. Normalized values of hip, knee and foot muscle torque force moments for study and control groups

Parameters		Climbers			Control group			p
		Mean ± SD	Me	CI 95%	Mean ± SD	Me	CI 95%	
FES [N·m]	R	0.93 ± 0.17	0.97	0.86-1.00	0.75 ± 0.18	0.79	0.67-0.84	0.002*
	L	0.99 ± 0.22	1.02	0.89-1.08	0.78 ± 0.18	0.84	0.70-0.87	0.002*
FFS [N·m]	R	2.96 ± 0.74	2.90	2.63-3.29	2.65 ± 0.57	2.56	2.38-2.91	0.139
	L	2.96 ± 0.68	2.83	2.66-3.26	2.85 ± 0.60	2.73	2.57-3.13	0.641
KES [N·m]	R	2.58 ± 0.55	2.53	2.34-2.82	2.76 ± 0.61	2.70	2.47-3.04	0.336
	L	2.59 ± 0.55	2.45	2.34-2.83	2.74 ± 0.73	2.69	2.40-3.08	0.441
KFS [N·m]	R	1.46 ± 0.20	1.45	1.37-1.55	1.60 ± 0.41	1.57	1.40-1.79	0.155
	L	1.43 ± 0.24	1.38	1.33-1.54	1.59 ± 0.49	1.51	1.37-1.82	0.174
HES [N·m]	R	1.37 ± 0.60	1.33	1.12-1.65	1.22 ± 0.34	1.19	1.06-1.38	0.286
	L	1.72 ± 0.64	1.66	1.43-2.00	1.33 ± 0.32	1.29	1.18-1.48	0.020*
HFS [N·m]	R	1.74 ± 0.49	1.66	1.52-1.96	2.13 ± 0.62	2.16	1.84-2.43	0.027*
	L	1.54 ± 0.63	1.42	1.26-1.81	1.80 ± 0.52	1.86	1.56-2.04	0.155

Legend: FES – foot extensors strength; FFS – foot flexors strength; KES – knee extensors strength; KFS – knee flexors strength; HES – hip extensors strength; HFS – hip flexor strength; CI – confidence interval; Me – median; R – right, L – left; * – $p \leq 0.05$.



Note: negative bars denote detrimental changes, CMJA – countermovement jump with arm swing height, Ext – knee extension for maximal torque, Flex – knee flexion for maximal torque, L – left, R – right, SLJ – standing long jump distance.

Figure 1. Interaction results of normalized foot flexor muscle torque force moments by group and side.

Table 4. The values of static and dynamic stabilographic parameters in study and control groups

Indices		Climbers			Control group			p
		Mean ± SD	Me	CI 95%	Mean ± SD	Me	CI 95%	
OSI	EO	0.61 ± 0.21	0.65	0.52-0.71	0.95 ± 0.34	0.85	0.78-1.11	<0.001*
	EC	1.84 ± 0.77	1.70	1.50-2.18	3.50 ± 1.99	2.85	2.56-4.43	<0.001*
APSI	EO	0.45 ± 0.16	0.45	0.38-0.52	0.68 ± 0.25	0.65	0.56-0.80	0.001*
	EC	1.32 ± 0.63	1.10	1.05-1.60	2.29 ± 1.07	2.05	1.78-2.79	0.000*
MLSI	EO	0.34 ± 0.14	0.35	0.25-0.40	0.52 ± 0.22	0.55	0.42-0.62	0.002*
	EC	1.00 ± 0.42	1.00	0.82-1.19	2.22 ± 1.43	1.85	1.55-2.89	0.001*
FRI	12-6	0.64 ± 0.21	0.65	0.55-0.73	0.98 ± 0.44	0.90	0.77-1.18	0.004*
	6-2	0.85 ± 0.34	0.80	0.70-1.00	1.54 ± 0.56	1.60	1.28-1.80	<0.001*

Legend: OSI – Overall Stability Index; APSI – Anterio-Posterior Stability Index; MLSI – Medial-Lateral Stability Index; FRI – Fall Risk Index; EO – eyes open; OC – eyes closed; CI – confidence interval; Me – median; * - $p \leq 0.05$.

Table 5. The correlation between the parameters of ankle joint extensor strength and selected balance parameters

	FES R	FES L
MLSI EC	R = -0.418; p = 0.006	R = -0.331; p = 0.032
FRI 6-2	R = -0.520; p = 0.004	R = -0.435; p = 0.0004

Legend: MLSI – Medial-Lateral Stability Index; FRI – Fall Risk Index; EC – eyes closed; FES – foot extensors strength; R – right; L – left.

Discussion

The primary finding of the conducted research is that climbing enhances the strength of specific muscle groups in both upper and lower limbs. Additionally, it probably has a positive impact on balance, as indicated by the values of static and dynamic stabilographic indices. To maintain group homogeneity and account for the greater popularity of bouldering among men, only male subjects were included in the study. All climbers involved in the study were athletes with at least 2 years of experience in bouldering. Observation showed that it is enough time to improve significantly in both physical and technical aspects of rock climbing. The lowest grade climbed by the participants was not declared; however, the highest grade climbed by one of the participants in our study was an 8A+ (Font scale) boulder with 12 years of experience. That correlates to V12 (Vermin scale). According to Draper et al. 2015, this correlates to an elite level male climber [19]. The members of the study group had both climbing experience in natural conditions and on artificial climbing walls. For comparison, people in the control group had no climbing experience.

A previous study showed that upper limb strength is the factor of a climber's high performance [6]. Moreover, the literature showed a significant role of hand and finger muscle strength [5, 7]. Ozimek et al. proved that finger strength in elite climbers correlates significantly with climbing level [20]. Results of our study showed that climbers had higher hand grip strength (HGS) with closed thumb compared to the control group. Interestingly, this was not demonstrated for thumbless clasp. While a hand dynamometer is widely acknowledged as a reliable tool for assessing hand grip strength (HGS), several researchers have observed a limitation in its ability to directly correlate with manual climbing proficiency. Consequently, they advocate the utilization of a hangboard or fingerboard as an alternative measure [20]. Given the inclusion of the control group comprising non-climbers, it was not feasible to mandate their proficiency in hanging on specialized equipment. In the current literature there is a lack of reports in regard to the involvement of lower limb muscle groups and their strength in climbing, especially in the bouldering discipline [9]. There is also a need for further stabilographic studies on climbers, as indicated by

previous research [21, 22]. The existing literature provides supporting evidence on how rock climbing impacts biomechanical factors in complex activities such as vertical jumps, squats, and foot pedalling [9]. Moreover, previous studies have shown improvements in vertical jump performance after a 4-week climbing training [8]. An important observation from our study is that the group of climbers showed greater strength in the thigh extensors compared to non-climbers, with statistically significant values observed only on the left side. From practical experience, it is probable that an increase in hip extensor strength may be attributed to the use of the heel hook (HH) technique. Walker explains the HH technique as the active use of the heel on a foothold, significantly engaging the hamstrings and gluteus maximus muscles, which results in a shift of the center of gravity in space, thus allowing climbers to reach a higher available hold on the wall or rock [23]. Moreover, in the post-hoc tests, statistically significant differences were found in the strength of thigh extensors between the limbs in climbers. The advantage of strength in the left limb may be explained by the fact that it served as the support limb for all participants, which played a more crucial role in maintaining stability. On the other hand, the right lower limb is likely to be more utilized for attacking, which could translate into better performance for climbers. Currently, climbing facilities worldwide are designed with three-dimensional formations, which requires climbers to engage their lower limbs in a more unique and complex way [24]. Rock climbers often perform dynamic movements, such as jumps or pull-ups, to overcome challenging climbing sequences [3, 5]. The strong extensor muscles of the left thigh and flexors of the right thigh may be related to the utilization of different climbing techniques. Additionally, this difference in strength might also result from previously practiced sports, social conditions, or the preferences of route setters on artificial climbing structures creating challenges (boulder problems). To add to the discussed data, it should be noted that climbers achieved lower values in the strength of thigh flexors compared to the control group. Moreover, advanced climbers can also be distinguished from elite climbers based on finger strength, which suggests not only comparing their lower limbs muscle strength with the control group, but also a division of climbers by skill level in subsequent studies [25].

Furthermore, climbers demonstrated a statistically significant advantage in the strength of both feet extensors compared to the control group, which may aid in bearing weight on the rock. This is likely related to the significant use of foot extensors in the toe-hook (TH) technique [26]. From the literature, it is evident that the most common injuries among climbers, especially those practicing bouldering, are related to the lower limbs. In particular, ankle joint injuries during falls are common [27, 28]. During daily functioning, the foot extensors primarily lift the foot during walking, and it should be noted that the foot is relatively light. By strengthening the foot extensor muscles, climbers can improve their ability to execute climbing techniques that heavily rely on these muscles, thus contributing to their overall climbing performance and advancement. Moreover, previous research shows that the MLSI EC and FRI 6-2 are the strongest diagnostic indicators of postural stability [29]. The results also demonstrated a statistically significant negative correlation between the strength of ankle joint extensors and the MLSI EC index (P: r = -0.42; L: r = -0.33) and FRI 6-2 index (P: r = -0.44; L: r = -0.52). This suggests that greater strength in the anterior compartment of the lower leg may contribute to better balance. It is possible that training of the anterior compartment affects proprioception of the retinacula of the extensors. Its supposed influence on balance [30] could also provide an explanation to these findings. From practical experience, that movement on the wall allows for shifting the center of gravity closer to the wall, which consequently reduces the strain on the upper limbs. The strength of foot flexors in climbers was also higher compared to the control group, even though not statistically significant.

Stronger extensors and weaker flexors indicate the presence of some form of muscle imbalance. Bouldering is a demanding and intense physical activity that may involve the risk of injury and straining of the muscles most involved during its practice. Lutter et al. demonstrated that climbers may suffer knee joint injuries while employing the heel hook technique (HH) [31]. Some of these injuries involve muscles of the hamstring group, especially the biceps femoris muscle, and the iliotibial band, which is attached to the gluteus maximus muscle [32, 33]. So, another result of the above research is the knowledge of which muscle groups are overloaded during prolonged practice of the sport. Strong muscles help maintain adequate joint stability and prevent excessive movement, but they can also lead to an imbalance between the forces acting on a given joint (Jeon et al. 2016). This, in turn, predisposes to the occurrence of injuries, and the role of trainers and physiotherapists is to strive for their prevention. Therefore, in planning the training for climbers, special attention should be paid to maintaining an appropriate distribution of the forces of thigh flexors and extensors, and appropriate anti-traumatic and preventive procedures should be developed.

The study showed that the climbers achieved significantly lower values of stabilographic indices compared to the control group, thus indicating their significantly better balance. The better balance is most likely due to a very good ability to control the projection of the center of gravity to maintain an optimal position while climbing [14] and to climb on a slab, where the wall is set at an angle of less than 90 degrees, which requires climbers to have significant technical and coordination skills but especially muscle strength and balance control to solve and pass a boulder problem. This is confirmed by Aras et al. [34], who showed better results in balance tests in climbers than in the control group, further indicating the need for more research in this area using other methods and tools. The research presented in this paper shows some of the first results in climbers using the Biodex Balance System (BBS) platform (USA) by comparing climbers and active non-climbers. Furthermore, Hosseini [21] evaluated the effect of warm-up intensity in climbers on balance using the BBS system, where they showed that higher warm-up intensity positively affected balance parameters. They observed the main changes in the value of the OSI index and pointed to the need to analyze the APSI and MLSI parameters. It is worth mentioning that the study by Aksit and Cirik [22] showed differences in balance in favour of more advanced climbers in comparison to intermediate climbers, further indicating the need to study balance under dynamic conditions and the correlation of balance with climbing-specific parameters, which was also demonstrated in our study (correlation of ankle and knee joint extensor strength with selected balance parameters).

The above-mentioned findings prove that regular training and experience of a climber contribute to improving postural stability, and indicate that climbing can be used as a therapeutic tool for various types of balance disorders and improving deep sensation. The study by Gassner [35] confirms this in a systematic review showing the positive effects of many forms of climbing on improving balance in some patients with various neurological disorders. The literature points to the positive effects of climbing training on many psychological and physical

aspects. One study analyzed the effects of climbing on levels of self-confidence and risk-taking in more than two hundred rock climbers [36]. It showed that climbers were characterized by high self-efficacy and were more willing to engage in riskier and more difficult climbing problems or routes the higher their level of climbing proficiency. It is important to note that while climbing positively contributes to the development of balance skills, it does not necessarily imply that it is a recommended training method for all individuals at risk of falls. Climbing may also find a use in patients with major depressive disorder. Researchers have shown that climbing improves emotion regulation shortly after climbing training compared to a control group that engaged in Jacobson relaxation training [37].

In conclusion, rock climbing positively affects many psychological as well as physical aspects. It can be applied when working with patients with muscle weakness and balance disorders. The above results indicate what muscle groups are crucial to be strengthened to increase the possibility to become stable and thus overcome more demanding bouldering problems. However, it is worth noting that rock climbing in bouldering discipline is a multi-dimensional sport that requires not only adequate muscle strength, but also coordination, technique or general endurance. Future reports should involve a larger study group to identify the importance of strength of specific muscle groups and balance in terms of climbing proficiency levels.

Conclusion

1. While bouldering enhances muscle strength, particularly in hand grip strength, hip and foot extensors, it is essential to recognize the potential for overload in these muscle groups.
2. Regular climbing training improves balance in both static and dynamic conditions in males; therefore, research should be continued to evaluate the effects of climbing on balance disorders.
3. Climbing can serve as a preventive tool against both muscle weakness and postural stability disorders.

Limitation of the study

Research should be extended to include a larger sample of climbers. Also, specialized measurement tools should be employed to assess upper and lower limb muscle strength. Additionally, climbers could be categorized based on established scales such as the International Rock-Climbing Research Association (IRCRA). This approach may provide valuable insights into the influence of climbing proficiency on the strength of specific muscle groups and postural stability across various levels of expertise.

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