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THE ROLE OF BODY BUILD, STRENGTH AND ENDURANCE ABILITIES IN ACHIEVING HIGH RESULTS BY ROCK CLIMBERS

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Authors' contribution:

A. Study design/planning
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D. Data interpretation
E. Preparation of manuscript
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Abstract:

Aim: the aim of this publication was to establish the importance of body build, strength and endurance abilities in achieving high results by climbers at higher elite/elite rock-climbing levels.

Method: The study comprised 15 climbers with elite [n = 9] and higher elite [n = 6] training. The age of elite climbers was at an average of 33 years with SD = 8.2 years, and higher elite was, on average, $\bar{x}$= 25.6 years, with SD = 7.6 years. The climbing efficiency was determined by the best RP and OS rock-climbing result in the last year. Selected somatic features were measured: body height, body mass, adipose tissue, upper limb length, circumferences of the forearm, arm, thigh and shank. Moreover, the following indices were calculated: Rohrer, slenderness and upper limb length. Finger strength was evaluated in the Grip-open 1 test. The absolute strength values were expressed per kg of body mass in the Grip-open 2 test. Fatigue resistance was measured in isometric contraction of the forearm muscles on a 2.5-cm hold - Hang 1, and 4-cm hold - Hang 2, while arm strength was assessed using the pull-up test.

Results: Higher levels of the upper limb length index was noted among climbers at the highest rock-climbing compared to the elite group. Moreover, in all of the conducted motor tests, higher elite climbers scored better than those elite. In these trials, high correlation coefficients were reported between the results of motor tests and the results of RP and OS. RP - Grip-open 2 = 0.71, OS - Grip-open 2 = 0.70, RP - Hang 1 = 0.68, OS - Hang 1 = 0.72, RP - Hang 2 = 0.67, OS - Hang 2 = 0.73. The RP result was explained in 63% by the system of variables: finger strength plus fatigue resistance in isometric contraction on a larger slat. On the other hand, the OS result was explained in 77% by the same system of variables.

Conclusions: Climbers with the highest rock-climbing level should have similar or even more favourable values of those somatic features considered significant than climbers representing the elite level. A high level of finger strength and fatigue resistance in isometric contraction of the forearm muscles significantly determines the effectiveness of climbing at higher elite/elite levels.

Introduction

Sport climbing is a dynamically developing discipline. It can be performed on an artificial wall or on rocks. In the case of rocks, the length of the climbing routes varies from several to several dozens of metres. Thus, the duration of such an effort ranges from tens of seconds to tens of minutes. Climbing routes are most often overcome in two styles: on-sight (OS) and rotpunkt (RP). OS style climbing has a longer duration of the effort than the RP climbing style. The average relationship between tension and relaxation of the forearm muscles is 4:1. However, depending on the nature of the route, these proportions may vary. It is assumed that when climbing in the OS formula, the contact time with the hold is longer than in the case of RP [1]. Climbing routes have their

difficulty measured on an applicable scale. Currently, the level of overcome difficulties reaches the level of 9c [1]. Elite climbers are people who undertake routes with difficulties from 8a + to 8c, and higher elite are climbers are those who tackle difficulties of at least 8c + [2].

As in every sports discipline, determinants are sought here that define the effectiveness of climbing in a particular way and at various stages of training. Currently, there are many existing scientific publications devoted to somatic, biomechanical, physiological and motor aspects within the context of climbing movement on an artificial wall or rocks [3,4,5,6,7]. The current results of research on body build and motor potential of a sports climber (studies using motor tests) indicate a significant role of low levels of fat, high indices of upper limb length, low circumference of the shank, high finger and arm strength, resistance to fatigue in isometric contraction of the forearm muscles and the strength endurance of the arms in achieving a good result in the discussed sport [1,6,7,8]. At this point, it should be added that these studies are carried out at various levels of sports training, e.g. beginners, elite or advanced. The comparison of results measuring the strength and endurance of beginner and elite climbers gives only information about the differences in motor determinants between the studied groups of climbers [7,8]. On the other hand, the correlational relationships or the coefficients of determination in the elite and advanced groups make it possible to answer the question as to which somatic and motor determinants determine the victory in a particular way, but in the group of climbers representing the elite and advanced climbing levels [6,7,8]. Therefore, on the basis of the above-mentioned information, we do not find an answer to the question as to what has particular impact on the effectiveness of climbing at the advanced elite/elite level. Thus, **the aim of this publication is to establish the significance of body build, strength and endurance in highly trained rock climbers**. In connection with the above objective, it was decided to pose the following research questions:

1. What are the somatic and motor characteristics of climbers representing the highest rock-climbing level?
2. Are there differences in the studied somatic features and motor skills in favour of higher elite climbers compared to those elite?
3. Are there significant correlation coefficients between the results of RP and OS in the group of higher elite/elite climbers as well as somatic features and the results of tests measuring strength and endurance?
4. What system of variables most strongly explains the variability of results in rock-climbing, both in the case of OS and RP, at the studied level of training - higher elite/elite?

Method

The study participants comprised 15 climbers with higher elite [n = 6] and elite [n = 9] training. The age of the higher elite climbers was as follows: = 25.6 years with SD = 7.6 years, and the age of those elite was at the level of 33 years with SD = 8.2 years. Climbing efficiency was determined by the best rock-climbing result of the RP and OS in the last year.

For somatic characterisation, the following somatic features were measured:

a) length: body height (v), upper limb length (a-da),
b) body circumference: largest circumference of the arm, greatest circumference of the forearm, greatest circumference of the thigh and shank.
c) body mass and body fat percentage. The measurement was performed using the Tanita TBF 583 scale.
d) body proportion indices: slenderness ratio, upper limb length index, Rohrer index [9].

Tab. 1. Rock-climbing level regarding RP and OS of the studied group of climbers.

No. of persons	RPscore	No. of persons	OSscore
1 person	9a+	1 person	8c
3 persons	9a	1 person	8b
2 persons	8c+	2 persons	8a+
		2 persons	8a
2 persons	8c	1 person	7c+
3 persons	8b	4 persons	7c
1 person	8a+	1 person	7b+
3 persons	8a	2 persons	7b
		1 person	7a+

The following motor skills were measured:

Finger strength - test performed according to of the guidelines by Michajlov et al. [9] with own modification for the dominant hand. The tested person stands on a scale under a 1.5 cm wide hold. The athlete grasps the ledge with four fingers without the thumb and tries to pull up on the hold. The absolute strength result is the weight unloading [Grip-open 1], while the quotient of the absolute strength and body mass is the result of the relative strength [Grip-open 2]. The examined person performs 3 attempts and the best result is recorded. [1]

Fatigue resistance in isometric contraction on 2.5- and 4-cm holds [Hang 1] - test performed according to guidelines by Ozimek, Staszkiewicz, Rokowski et al. [10]. The tested person stands under a 2.5-cm wide hold, grabs it with both hands and four fingers without using the thumb - the arms are shoulder-width apart and straightened in the elbows. Upon the researcher's signal, the subject lifts his/her legs off the ground. The task of the subject is to hang on the test hold as long as possible. The hang time is measured in seconds. Apart from the overhang on a 2.5 cm wide hold, a measurement was carried out on a 4-cm wide hold [Hang 2].

Finger strength and strength tests of the forearm muscles were carried on a wooden hold. The 1.5-cm edge of the hold was rounded with a 3.5-mm radius, and in the case of the 2.5-cm hold, the edge had a 4-mm radius. On the other hand, the edge of the 4-cm hold was rounded with a radius of 5.5 mm. The intervals for resting between tests were complete. Due to the extensive training experience, the climbers themselves decided when to start a given trial.

Strength endurance of upper limbs [Pull-ups] - test performed according to the International Physical Fitness Test [11].

Statistical analysis included:

1. Assessment regarding the level of development concerning somatic and motor parameters among the studied groups of climbers, on the basis of arithmetic means and measurements of variability.
2. Determining the significance of differences for independent variables using the Student's *t* or Mann-Whitney test. The normality of distribution was checked with the Shapiro-Wilk test.
3. Calculation of the linear correlation coefficients (Pearson's test) between the individual results of motor tests.
4. Testing the strength of the relationship between the level of all the examined parameters and climbing efficiency using rank correlation coefficients (Spearman's test).
5. Investigation of correlation strength between the results of motor tests using Pearson's correlation coefficient.
6. Application of multiple regression analysis to determine the combined effect of variables on climbing efficiency. The method of progressive stepwise regression was used. As the number of the studied subjects was small in relation to the number of independent variables, R^2pop was calculated in accordance with the method recommendations. Variables with the highest correlation coefficient were successively entered into the model. Critical values for the F statistic at the significance level of $p \leq 0.05$ were adopted.

Results

In the research conducted by the authors, no statistically significant differences were found between the group of climbers representing the higher elite and elite levels for the majority of the tested somatic features. The only statistically significant difference in favour of higher elite climbers concerned the upper limb length index. At this point, it should be noted that in the conducted research, despite statistically insignificant differences, higher elite climbers were characterised by lower body mass, body fat and leg circumferences than elite climbers. On the other hand, the group of masters was characterised by larger circumferences of the arm and forearm. Moreover, both groups demonstrated an athletic body build type based on the Rohrer index. However, according to the slenderness ratio, the climbers from both groups were characterised by slender build.

In the majority of cases, no significant correlation coefficients were found between the examined somatic features and the results of RP and OS in rock-climbing level. The only statistically significant relationship could be observed in the upper limb length index. It is worth noting, however, that the correlation coefficients of the rock-climbing level with body mass and the level of fat as well as the circumferences of the thigh and shank were negative, and in the case of the circumference of the forearm and upper arm - positive.

For the majority of the tested motor skills, statistically significant differences were found in favour of climbers representing the highest sports level. At this point, it is worth noting that higher elite climbers had a significantly higher level of strength, both in absolute and relative terms. Moreover, they had a higher level of resistance to fatigue in isometric contraction on both the smaller and larger holds. Higher elite climbers also had a higher level of arm strength endurance.

In this study, significant correlation coefficients were noted between the tested motor skills and the results of RP and OS. Particularly noteworthy are the correlation coefficients for finger strength in relative terms. This applies to the RP and OS rock-climbing score. Moreover,

Tab 2. Somatic features of the studied rock-climbers and differences between groups.

	higher elite			elite		
Variables	$\bar{x}$	SD	V%	$\bar{x}$	SD	V%
Body height [cm]	174.16	4.40	2.52	175.22	5.84	3.33
Body mass [kg]	64.0	4.42	6.90	66.20	6.29	9.51
Percentage of fat content [%]	8.41	1.96	23.34	10.30	5.29	51.44
Slenderness ratio	43.57	1.29	2.96	43.39	1.15	2.65
Rohrer coefficient	1.21	0.10	8.73	1.23	0.13	10.80
Length of upper limb [cm]	78.6	1.96	2.49	76.66	2.95	3.85
Length index of upper limb	45.16**	0.80	1.77	43.77	0.64	1.47
Arm circumference [cm]	29.83	1.50	5.04	28.05	2.45	8.75
Forearm circumference [cm]	29.00	1.26	4.361	27.72	1.98	7.16
Thigh circumference [cm]	51.16	1.60	3.13	51.56	3.22	6.25
Shank circumference [cm]	34.50	2.25	6.54	35.87	1.48	4.13

**$p \leq 0.01$, *$p \leq 0.05$ – Student's t

Tab. 3. Linear correlation coefficients between the examined somatic features and rock-climbing level.

	RP	OS
Body height [cm]	-0.32	-0.30
Body mass [kg]	-0.29	-0.27
Percentage of fat content [%]	-0.26	-0.37
Slenderness ratio	0.13	0.10
Rohrer coefficient	-0.12	-0.09
Length of upper limb [cm]	0.10	0.10
Length index of upper limb	0.66*	0.68*
Arm circumference [cm]	0.30	0.34
Forearm circumference [cm]	0.21	0.30
Thigh circumference [cm]	-0.11	-0.10
Shank circumference [cm]	-0.36	-0.39

*$p \leq 0.05$

high correlational relationships were noted between the RP and OS scores and the resistance to fatigue in isometric contraction on both smaller and larger holds. It should be added that slightly higher correlation coefficients between the result in the rock-climbing and endurance tests were noted for OS style of climbing.

In the present study, statistically significant relationships were found between the results of relative strength and the results of resistance to fatigue in isometric contraction on 2.5 holds ($r = 0.72$). Moreover, statistically significant correlation coefficients were noted between the results of resistance to fatigue in isometric contraction on the 2.5- and 4-cm holds ($r = 0.63$).

In order to accurately determine the role of strength and endurance in sports climbers, a multiple determination model was used. In the research, it has been shown

Tab. 4. Strength and endurance characteristics of the studied climbers and differences between groups.

	higher elite			elite		
Variables	$\bar{x}$	SD	V%	$\bar{x}$	SD	V%
Grip-open 1 [kg]	62.41*	8.779	14.06	50.95	7.06	13.85
Grip-open 2 [kg/kg]	0.98***	0.124	12.61	0.76	0.052	6.86
Hang 2.5 cm [s]	112.50***	14.12	12.55	78.11	10.33	13.23
Hang 4cm [s]	154.66*	21.70	14.03	115.33	31.75	27.53
Pull-ups [n]	28.50 ^ ^	3.61	12.69	24.77	2.43	9.83

***$p \leq 0.001$,**$p \leq 0.01$, *$p \leq 0.05$ – Student's t, ^ ^ $p \leq 0.01$ – Mann-Whitney

Tab. 5. Linear correlation coefficients between the motor effects of strength as well as endurance, and the rock-climbing level.

Variables	RP	OS
Grip-open 1 [kg]	0.47	0.48
Grip-open 2 [kg/kg]	0.71*	0.70*
Hang 2.5 cm [s]	0.68*	0.72*
Hang 4cm [s]	0.67*	0.73*
Pull-ups [n]	0.47*	0.51*

*$p \leq 0.05$

Tab. 6. Pearson's linear correlation coefficients between selected results of strength and endurance tests.

Variables	Grip-open 1	Grip-open 2	Hang 1	Hang 2	Pull-ups
Grip-open 2	0.83***	1.00	0.72**	0.35	0.11
Hang 1	0.46	0.72**	1.00	0.63*	0.44
Hang 2	0.09	0.35	0.63*	1.00	0.55*

*$p \leq 0.05$, **$p \leq 0.01$,***$p \leq 0.001$

Tab. 7. Linear regression coefficients between the RP result and the results of strength and endurance tests.

Variables	R	R^2	R^2pop	Std. error of estimation	F	p
Grip-open 2	0.72	0.51	0.48	1.78	13.67	0.002
Hang1	0.66	0.44	0.4	2.30	10.26	0.000
Hang 2	0.64	0.40	0.36	2.10	8.93	0.010

Tab. 8. Linear regression coefficients between the OS result and the results of strength and endurance tests.

Variables	R	R^2	R^2pop	Std. error of estimation	F	p
Grip-open 2	0.75	0.57	0.53	1.68	17.09	0.001
Hang 1	0.70	0.50	0.46	1.81	13.09	0.003
Hang 2	0.73	0.54	0.50	1.74	15.15	0.001

that both in the case of the RP and OS styles of climbing, the best explanation for the variability of results is the system of finger strength in relative terms plus resistance to fatigue in isometric contraction on a larger hold. It should be noted here that the Hang 1 test result did not qualify for the model at all. It seems that such an effect is due to the strong correlation between the results of the finger strength test and the results of the test measuring

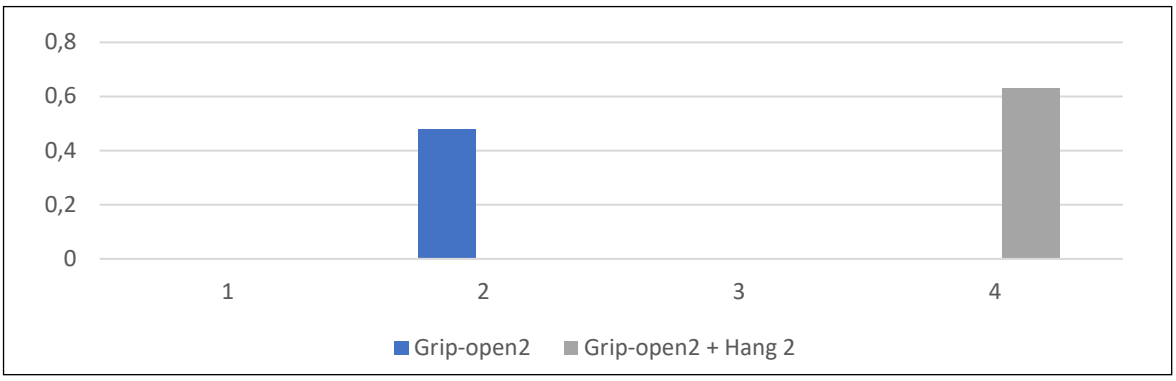

Fig. 1. Multiple determination coefficient between RP score in rock-climbing and the tested motor effects

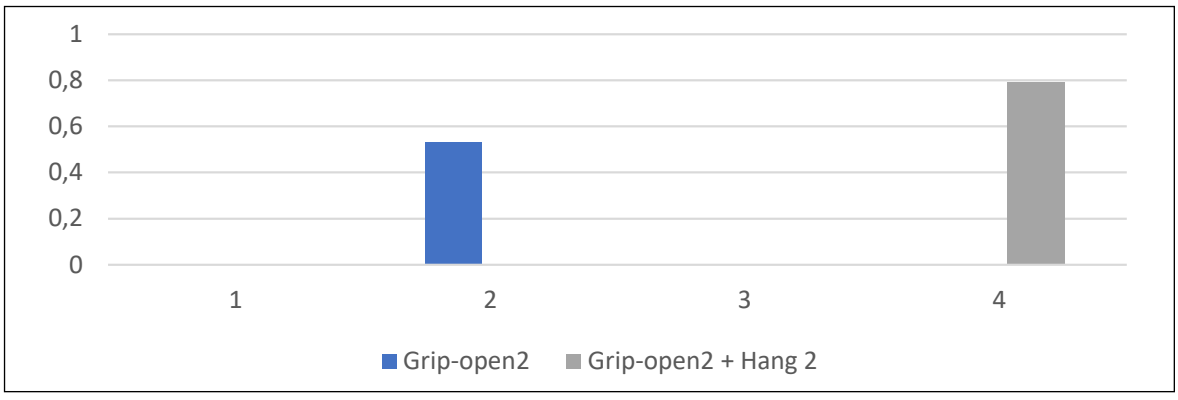

Fig. 2. Multiple determination coefficient between OS score in rock-climbing and the tested motor effects

resistance to fatigue on the 2.5-cm wide hold. The correlation coefficient in the comparison of finger strength - Grip-open - 2, and the resistance to fatigue in isometric contraction on the 2.5-cm hold was $r = 0.72$. Thus, climbers who had high levels of finger strength also had a high level of endurance in the test using a smaller hold.

Discussion

The scientific observations to date show that the following somatic features play an important role in the discussed sport: low body mass, low fat level, low shank circumference, high slenderness ratio and high upper limb length index [1,3,12,13]. In addition, motor skills play a significant part: those strength- and endurance-related. The strength of the fingers and fatigue resistance in isometric contraction of the forearm muscles are of particular importance [6,7,8,10]. At this point, it should be noted that to determine the role of body build and ability in scientific observations, the comparison of climbers is most often made without taking into account the results of higher elite climbers – e.g. elite with lower or elite with advanced grade [7,8]. Such a combination provides an answer to the question as to what determines the effectiveness of climbing, but only at the tested level of training. On this basis, it is difficult to judge what distinguishes climbers at the highest level of advancement in a special way. In addition, the use of correlation coefficients in groups of climbers at a given climbing level provides information on the priority determinants of success, but only at the specifically tested training level – e.g. lower grade or elite [8]. Here, it should be emphasized that the literature on the subject lacks research comprising climbers representing the highest rock-climbing level. These studies include those conducted by Rokowski and Ręgwelski [1], Michajlov et al. [9] and Balaś et al. [14]. Therefore, the aim of the study was to determine the significance of body build, strength and endurance abilities of high-level climbers. Attempts to carry out this research objective were made by comparing the results obtained higher elite and elite climbers. And secondly, through the use of correlation coefficients and multiple determination in the study group of higher elite/elite climbers.

In the authors' study, the climbers presenting the higher elite level of advancement may be considered those with long upper limbs in relation to body height. These climbers had a significantly higher level of the upper limb length index compared to the group of elite climbers. Such research results suggest that one of the more important somatic features that can distinguish climbers

at the highest level of training in both OS and RP climbing is a high level of the above-mentioned index. However, at this point, it should be noted that in the research conducted by Rokowski and Ręgwelski [1], climbers with a lower rock-climbing level were also characterised by a high level of the discussed index. Therefore, on the basis of the scientific research conducted so far, we are tempted to express the view that climbers presenting the highest rock-climbing level should be characterized by long upper limbs in relation to body height. On the other hand, whether the examined somatic feature is a priority factor and, in a certain way, is decisive in the success of rock-climbing at the highest level, it seems that this requires further empirical verification.

It should also be noted that in the presented study, despite the lack of statistical differences, higher elite climbers were characterised by lower body massand body fat, lower thigh and shank circumferences, and larger arm and forearm circumferences than the elite group. Moreover, considering the body type of the master class climbers, athletic-leptosomic body structure was characteristic. Summarising the above research results, it may be concluded that rock-climbers representing the highest level should have similar or even more favourable values of the somatic features mentioned above than climbers representing the elite level. It should be noted that in rock climbing, as in any other sports discipline, a phenomenon of feature compensation exists. This view, within the context of rock climbing, was expressed, among others, by Rokowski [8] or Magiera et al. [15]. For example, Rokowski and Ręgwelski [1], presenting various results of scientific studies devoted to the body structure of a sports climber, formulated the thesis stating that "in sports climbing, a competitor with a slightly worse body build may also achieve very good results by compensating for these deficiencies through above-average motor potential".

In the authors' research, it has been shown that higher elite climbers have a much higher level of finger strength than climbers representing the elite level. Similar research results were obtained in the comparison of elite/advanced climbers with lower grade, and elite with advanced [8,6]. Moreover, in the presented study, high correlation coefficients were noted between the results of the finger strength test in the specific position of the hand on the hold, and the OS and RP score. Additionally, it is worth noting that the strength factor qualified for the multiple determination model from the first place and explained the variability of the results in 53% for OS-style climbing and 48% for RP-style climbing. Thus, the above research results show that climbing at higher elite/elite levels requires the highest values of finger strength. Moreover, it is indicated that this ability is a significant determinant of the effectiveness of climbing at the examined rock-climbing level. At this point, it is worth noting that significant correlation coefficients were also found between the value of finger strength and the rock-climbing score in studies on a lower level of training [8]. Therefore, one may be tempted to express the statement that motor skills significantly influence the result at various levels of climbing advancement.

In this study, it was found that higher elite climbers had a significantly higher level of resistance to fatigue in isometric contraction on both smaller and larger holds. Moreover, high correlation coefficients were noted between the OS and RP results and the results of endurance tests. The obtained test results prove that this type of endurance should distinguish climbers with the highest rock-climbing level in a special way. Furthermore, this ability is a significant determinant of climbing effectiveness at a high level of training. It is also worth mentioning that the duration of the 2.5- and 4-cm tests was different. Taking into account general regularity regarding physical effort, it may be assumed that this difference resulted, among others, from the specific pattern of muscle recruitment and other metabolic processes occurring in the muscles during test efforts. Moreover, it should be added that the test result on a 2.5-cm hold was more strongly determined by the force factor than the test result on a 4-cm one. At this point, it should be noted that in the studies carried out in the group of climbers at the training level: advanced-elite, similar results were obtained [7,8]. Therefore, on the basis of our own and other authors' research, it may be expressed that resistance to fatigue in isometric contractions, both on larger and smaller holds, as well as the relative strength of the fingers, is an important component of the effectiveness of climbing at various levels of climbing advancement.

Additionally, in the research by Rokowski and Żak [16], it was shown that elite climbers should have a high level of strength endurance in the arms. In this study, it has been indicated that climbers representing the highest level of training, the so-called higher elite, should have a similar or even higher level of said motor ability.

The system of determinants explaining the variability of the results during OS and RP climbing is the same. The model explaining the variability of the score consists of the following variables: finger strength scores plus larger grip strength test scores. At this point, it is appropriate to explain the lack of results in the model of the test carried out on a smaller hold. Well, this apparent lack of Hang 1 test results does not mean that the resistance to a smaller grip does not affect the result during OS and RP climbing. To the contrary, the impact of this type of strength is of great importance, as evidenced by the high coefficients of Spearman's linear correlation between the results of the Hang 1 test and the OS - $R = 0.72$ and RP - $R = 0.68$ rock-climbing levels. Thus, as noted above, this apparent lack of determination of the Hang

1 test results in the model should be explained by the strong correlation between the results of this test and the results of the strength test, which qualified for the model from the first place. The analysis of the results of this trial allows us to conclude that climbing both in the OS and RP formula at a high rock-climbing level is significantly conditioned by a high level of finger strength and endurance of the forearm muscles. On this basis, the authors demonstrate that the endurance factor is slightly more significant in the case of OS climbing. This is evidenced by, among others, higher correlational relationships than in the case of climbing in the RP formula which were noted between the result of OS and the results of endurance tests. This phenomenon should be associated with the fact that OS climbing is characterised by longer contact time with the hold and longer climbing duration than in the case of the RP version [1].

Conclusions

1. Higher elite climbers should have similar or even more advantageous values of the tested somatic features than climbers representing the elite rock-climbing level. One of the features that probably distinguishes them in a special way is the upper limb length index.
2. A high level of finger strength and resistance to fatigue in isometric contraction of the forearm muscles significantly determines the effectiveness of climbing at the higher elite/elite level.
3. The system of determinants explaining the variability of the results during OS and RP climbing at the studied level of higher elite/elite training is similar. It should be noted that the strength factor is slightly more significant with regard to the OS climbing formula.

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