

ANTHROPOMETRIC AND STRENGTH CHARACTERISTICS OF WORLD-CLASS BOULDERERS

Michail L. Michailov¹ (A,B,C,D,E,F), Lubomir V. Mladenov² (A,B,F), Volker R. Schöffl³ (D,E,F)

¹Department Theory of Sports Training, National Sports Academy, Sofia, Bulgaria

²Department Sports Medicine, National Sports Academy, Sofia, Bulgaria

³Klinikum Bamberg, Sozialstiftung Bamberg, Germany

Abstract

Introduction: Anthropometric profiles of lead climbers and boulderers may vary, nevertheless the anthropometric and strength characteristics of world-class boulderers have not yet been analysed. The purpose of this study was to determine these characteristics in elite boulderers competing in Bouldering World Cup.

Methods: Eighteen male (age 25.8 ± 5.1 years) and seven female (age 25.1 ± 5.3 years) competitors were studied at the 2007 Bouldering World Cup in Sofia, Bulgaria. Anthropometric parameters (height, body mass, body mass index, % body fat, % muscle mass and grip strength) were gathered and a sport-specific strength test was performed.

Results: Compared with results in the literature, these adult elite boulderers showed similar characteristics to elite sport climbers. For women the values of the anthropometric variables were: height (cm) 162.6 ± 11.6 , body mass (kg) 54 ± 6.8 , body mass index 20.4 ± 1.1 , % body fat 16.6 ± 3.6 , % muscle mass 41.6 ± 4.3 , grip strength (kg) 28 ± 8.7 , specific strength (kg) 21.6 ± 3.2 . For male climbers they were: height (cm) 174.6 ± 5.6 , body mass (kg) 67.3 ± 6 , body mass index 22 ± 1.4 , % body fat 5.8 ± 1.8 , % muscle mass 47.4 ± 1.8 , grip strength (kg) 58.6 ± 11.4 , specific strength (kg) 37.7 ± 6.9 . Correlation analysis did not lead to an identification of protrude factors in competition performance. Most of the correlations between the ranking and the measured variables were poor. Moreover the correlations (r) between the rankings from the previous World Cup and the one in Sofia were moderate ($r = 0.46$, $P < 0.05$, male rankings).

Conclusion: These world-class competition boulderers differed from elite sport climbers as they had higher percentage of body fat and greater hand strength, while the other anthropometric factors were similar. As the competition performance comprised of a series of elimination rounds whereby boulderers climbed unknown routes without any previous route rehearsal, performance success depended on the mutual action of multiple physical and mental factors. In various conditions different combinations of the decisive factors could be successful. Therefore performance is not stable during different stages of the World Cup.

Key words: bouldering, sport climbing, factors of performance

Introduction

Although the introduction of novel achievements into training theory and methodology is a difficult task, research of unexplored and new sport disciplines can further contribute to expanding the knowledge in this field. Based on its unique character and growing popularity sport climbing has been the subject of many scientific studies in recent years. However, most climbers regularly participate in a variety of climbing types – bouldering, sport, ice climbing, Alpinism – and most climbing studies do not seek to establish which is the dominant form of climbing in their subjects. Bouldering as a distinct climbing subdiscipline with its own scientific literature is rare in spite of its growing global popularity. Based on the fact that climbing is a poly-structural physical activity and leads to unique physiological reactions it is difficult to evaluate the performance limiting factors, of which many are still not verified (1-4).

One factor for performance success was the anthropometrical profile of the athletes, which was subject

of a few studies in recreational and elite rock climbers as well as competitors in lead climbing (sport climbing) (5-9).

However, the anthropometrical and strength characteristics of world-class boulderers have not yet been determined. This may also be partly due to the fact that the status of bouldering has only recently been elevated to a global stage. In 2006 it was included as a climbing competition discipline of the International Federation of Sport Climbing (www.ifsc-climbing.org), though this type of climbing has been practiced by climbers and alpinists as a preparatory mean or as a separate discipline, and many national and regional bouldering competitions have existed before that time (Fig.1).

Bouldering refers to ropeless rock climbing on boulders, bases of cliffs or artificial structures. The climbs are short in distance and a fall should not result in a serious injury. Mattresses and spotters are used for protection. Bouldering emphasises on the ascent of routes, where to maintain a balanced position is extremely difficult. A short sequence of unique and very powerful moves is



Fig.1. One of the world's best competitors in the bouldering discipline in action during the Bouldering World Cup in Sofia 2007

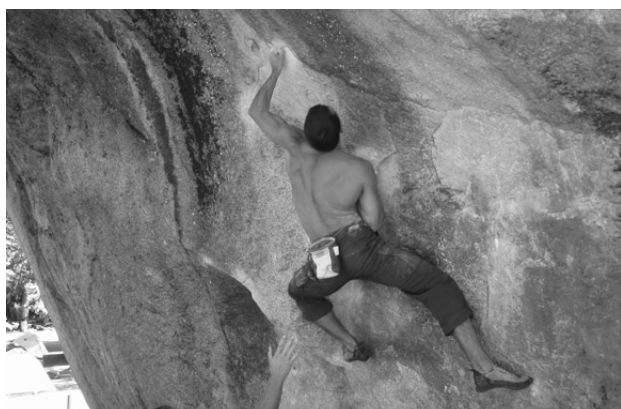


Fig. 2. Outdoor bouldering

used, with the body's mass sometimes only supported by small parts of finger tips or toes as well. Therefore it demands very high levels of specific maximal and dynamic strength, a powerful physique that this neither over- nor underdeveloped to limit loading on extremities of the body, and a determined mental focus to complete and puzzle out the best manner to achieve the route without also risking injury (Fig. 2). However these intense moves are often repeated many times and bouldering has an increased risk of injury to the fingers (10, 11).

The aim of the present study was to determine the anthropometric and strength profile of elite boulderers competing in the Bouldering World Cup and to evaluate how the different variables influenced competition performance.

Methods

The Bouldering World Cup in Sofia 2007 provided an ideal opportunity to access the world elite. Similar conditions were used by Watts et al. (8), in order to define the anthropometric profile of elite sport climbers. However, these conditions limit the range of the tested variables as the study must be designed to not interfere with competition performance.

Participants in the study were recruited from the competitors of the qualification round of the Bouldering World Cup. Of 56 male and 35 female boulderers, 18 (32%) male climbers from 10 countries and 7 (14%) female climbers from four countries recalled.

Questionnaire

The following data were collected through verbal interview: Age, years of climbing experience, best ever accomplished climbing achievements in bouldering and sport climbing (French grades of difficulty in bouldering and onsight and redpoint for sport climbing), hours of training per week (climbing and additional activities), dominant type of climbing (bouldering, sport climbing, both) and if they also focus on multi-pitch climbing.

The bouldering and sport climbing rating systems were transformed into numerical scales to enable calculation and statistical analysis according to Watts et al. (8) (Table 1).

Anthropometric measurements

Anthropometric measurements were performed in the warm-up area before the competitors began in accordance to the standardized anatomic locations and methods. Body mass was determined with a portable electronic scale (Tanita BF-666, Tokyo, Japan) with

Table 1. Numerical codes responding to different grades of difficulty in both sport climbing and Bouldering

French rating	7a	7a+	7b	7b+	7c	7c+	8a	8a+	8b	8b+	8c	8c+	9a
Numerical code	2.50	2.75	3	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50

the subjects barefoot and wearing minimal clothing. Skinfold thickness was measured using a Lange caliper by a single trained technician. The percentage of body fat was gathered via the equations of Jackson & Pollock (12), where skinfolds at three sites are used (triceps, supra-iliac and thigh for female subjects; chest, abdomen and thigh for male subjects). Percent muscle mass was determined using the anthropometric skeletal muscle mass prediction model of Lee et al. (13), where height, age, sex, ethnicity, skinfold thickness at the sites of the triceps, thigh, and calf, as well as circumferences of the arm, thigh and calf are taken into consideration. Grip strength was measured in three trials for both hands via a flat spring dynamometer (DRP 90, Gost 22224-76, Russia). The subject stood in an upright position with arm next to the body (not touching it) extended in the elbow joint. The maximal right and left side scores were recorded, summed and then divided by two.

Specific strength

To determine sport-specific strength a method first described through Köstermeyer and Weineck and further evaluated through Schöffl et al. was used (14, 15). The athletes were asked to stand on electronic scales and to hold with two fingers (middle and ring finger) of the dominant hand onto the smaller edge (10 mm deep) of the specific handhold (HRT safety holds, training hold model B, Sofia, Bulgaria). The competitors had to transfer their body mass from the scales to the hold by flexing their legs (Fig. 3). Specific maximum strength was calculated by subtracting the remaining value shown on the scales from the body mass. It is known that through the quadriga effect the isolated action of a finger may vastly increase (up to 48 %) the strength which the finger develops compared with its strength which can be reached by the participation of four fingers (16). Despite this and considering the high levels of finger strength of the competitive boulderers the sport-specific strength test in this study included the use of only two fingers

to insure that no participant will manage to hang on the hold. In such case when the legs are lifted off the ground the strength can not be measured. Although the method is simple, this is an easy and reproducible way to determine the sport-specific strength of a climber. Other authors who also measured specific strength used different devices (5, 16-21), nevertheless these are lacking comparability and reproducibility. Using accessible standard holds guarantees a comparison of the results in between different studies.

Statistical analysis

The data were sorted by gender and were subjected to descriptive analysis. The mean, maximum and minimum values, as well as the standard deviations (SD) and coefficients of variance (%V) were taken into consideration. For calculation of %V the equation $\%V = SD / \text{mean value} \cdot 100$ was used. Rank correlation coefficients of Spearman were calculated to determine the relationships between the different variables and four types of performance (rank in the Bouldering World Cup in Sofia, the most difficult boulder problem climbed outdoors, best onsight and red point). As there were only seven investigated women, correlation analysis for this group was not performed. Rank correlation was estimated also between the ranks in the present competition and the previous round of the World Cup in Erlangen, Germany.

The comparison of the investigated variables was done based on the logical analysis due to the fact that the used data concerning sport climbers (elite and recreational) is not collected during this investigation. Moreover the estimation of values of parameters like percentage of body fat and hand strength is often done by different authors using different equations, devices and methods. Some of the publications on climbing are relatively old and climbing has changed during the last years. Therefore only major differences between the values of the present study and results in the literature are taken into consideration.

Results

The dominant type of climbing performed by the subjects is presented in Fig. 4. Thirty-nine percent of the male competitors also climbed multi-pitch routes. No female competitor climbed multi-pitch routes.

The mean, maximum and minimum values, standard deviations and coefficient of variance of the different variables are presented in Table 2 and Table 3.

The subjects were not selected on a lottery principle. Statistically, they cannot be considered as a representative sample of all elite competitors. However, the tested male competitors were normally distributed by rank. Skewness 0.668, kurtosis -0.097 and Kolmogorov Smirnov Z 0.422 ($\alpha = 0.994$). According to these results, it could be logically assumed that the mean



Fig. 3. Execution of the sport-specific test for maximal strength assessment

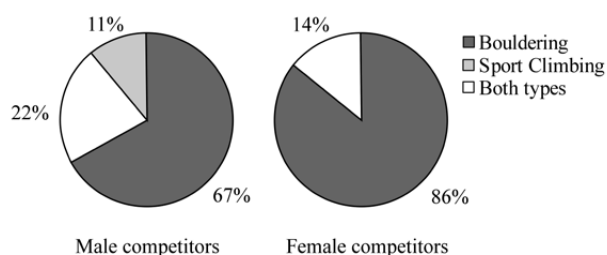


Fig. 4. Dominant types of climbing among male and female participants in the study

values of the different variables of the 18 boulderers are probably very similar to the mean values of the same variables of the general population of elite competitors in the Bouldering discipline.

Most correlations between the ranking in Sofia and the measured variables of the male competitors did not reach significance. Higher and significant coefficients did exist between ranking and age ($r = -0.56$, $P < 0.05$,

$n = 18$), ranking and experience ($r = -0.59$, $P < 0.01$, $n = 18$) and ranking and height ($r = 0.49$, $P < 0.05$, $n = 18$). Significant correlations were also present between the highest boulder grade ever climbed outdoors and the specific strength ($r = 0.61$, $P < 0.05$, $n = 13$) and specific relative strength ($r = 0.63$, $P < 0.05$, $n = 13$). The correlations between the rankings from the first World Cup (2007) in Erlangen, Germany and the second in Sofia were moderate ($r = 0.46$, $P < 0.05$, $n = 22$ men rankings; $r = 0.33$, $n = 18$ women rankings).

Discussion

It is well known by the climbing society that some climbers cope well with different types of climbing. Even for climbers specialized in a given climbing discipline complex training, variety of training load and methods and practicing different types of climbing are crucial for a performance improvement as every route

Table 2. General characteristics of world class boulder climbers

Variable	Gender	n	Min	Max	Mean	SD	%V
Age (years)	male	18	20	39	25.8	5.1	19.7
	female	7	16	30	25.1	5.3	21
Experience (years)	male	18	5	23	13.2	5.6	42
	female	7	7	15	10.7	2.9	26.8
Highest Boulder grade	male	17	3.3*	5*	4.3*	0.5*	10.4
	female	6	2.8*	3.8*	3.3*	0.3*	10.3
Best onsight	male	16	3.3*	4.5*	4.2*	0.3*	7.5
	female	4	2.5*	3.5*	3.1*	0.5*	15.3
Best redpoint	male	15	3.8*	5.5*	4.8*	0.5*	9.8
	female	5	2.8*	4.*	3.6*	0.5*	14.4
Training volume (h/week)	male	18	5	30	15.4	5.9	38.5
	female	7	8	20	11.6	3.9	33.8

* Numerical codes responding to different grades of difficulty in sport climbing and bouldering (see Table 1)

Table 3. Anthropometric and strength characteristics of world class boulder climbers

Variable	Gender	n	Min	Max	Mean	SD	%V
Height (cm)	male	18	165.7	187.3	174.6	5.6	3.2
	female	7	146.2	176	162.6	11.6	7.1
Body mass (kg)	male	18	55.8	75.6	67.3	6	9
	female	7	45.7	64.5	54	6.8	12.6
Body mass index	male	18	19.9	24.4	22	1.4	6.2
	female	7	18.2	21.4	20.4	1.1	5.5
Body fat (%)	male	18	3.4	10.6	5.8	1.8	31.1
	female	7	12.1	21	16.6	3.6	21.4
Muscle mass (%)	male	18	44.8	50.4	47.4	1.8	3.8
	female	7	35.9	49.3	41.6	4.3	10.3
Grip strength (kg)	male	14	43	76	58.6	11.4	19.4
	female	7	10	37	28	8.7	31.2
Specific strength (kg)	male	14	25.7	49.4	37.7	6.9	18.2
	female	7	17.9	25.4	21.6	3.2	14.6
Relative grip strength (grip strength to body weight ratio)	male	14	0.6	1.3	0.9	0.2	20.7
	female	7	0.2	0.7	0.5	0.1	27.6
Relative specific strengt (specific strength to body weight ratio)	male	14	0.4	0.8	0.6	0.1	18.4
	female	7	0.3	0.5	0.4	0.1	17.4

climbed will be unique in its presentation and technical demands. It is also known that one-sided training and continuously performing specific training loads leads to a detention of the trainable components and possible overuse injuries. Nevertheless, the questionnaire results demonstrate that competition-bouldering has reached a stage, where specialized training was needed to achieve excellence (Fig. 4). However the training hours per week do not correspond to the training volume of other world class athletes, e.g. world class rowers (22) or others and bouldering cannot be compared to Olympic sports yet. Nevertheless also other climbing studies showed comparable few training hours per week in elite climbers. Ten members of the German Junior National Team have trained only 8.9 ± 3.5 (h/week) in 1999 and 11.4 ± 3 (h/week) in 2004 (23). The training volume of American climbers with ranking 5.6 – 5.13c (Yosemite decimal scale) was 7.2 ± 5 (h/week) (6). Climbing frequency of elite climbers with mean onsight level 8b was 3.8 days per week (9). Nevertheless based on the maximum strength focus of bouldering and its required long regeneration periods a relatively small amount of training hours per week seems to be enough to reach high standards.

In scientific literature rock climbers were generally described as being relatively small in stature and having a very low percentage of body fat. Some studies presented climbers as excessively lean (7, 8), while other studies show that they are lean, but reflect similar data to other lean sports (5, 6). The small percentage of body fat was traditionally considered to be a predictor of climbing performance, because the excess fat will increase the muscle efforts during upward progress. This does not seem to apply to elite sport climbers (9). Sport climbers are lean but the percentage of body fat does not correlate significantly with climbing performance (19). Although boulderers do have a small percentage of body fat as well, no significant positive or negative influence onto the performance was found in the present study.

Unexpectedly, climbers' hand grip strength measured via dynamometer does not differ from non-climbers, because of the non-specific grip position in this test (4, 5, 6, 8). As an exception the grip strength of the female elite sport climbers is bigger compared with the general population (8). Times to exhaustion during static hand-grip endurance exercise were similar for trained and untrained climbers (24) but recovery during intermittent forearm contractions is higher in climbers (25) and climbers can perform rhythmic isometric contractions longer than non-climbers (24, 26). Elite climbers are also stronger with the left hand (which is more often the non-dominant hand) than recreational climbers and non-climbers (5). The reason is probably connected to the fact that climbing develops strength and agility for both hands. It can be assumed that grip strength is a factor that should not be underestimated in climbing, which also was found through Watts et al. (8). However,

relative strength and the specific strength of the climbers play a more important role. The two variables differ significantly from the control groups (5, 7, 8).

The sport-specific strength manifests by the use of two basic climbing grip positions. The crimp grip is applicable for holding small sharp edges in order to compensate the different length of the fingers and to avoid cutting the skin. According to Schweizer the most effective angle in the proximal interphalangeal (PIP) joint for developing the most powerful contraction is 90° and 110° (16). The slope grip is used to hold round grips and finger pockets. This grip position theoretically requires much lower muscle force to reach equilibrium with the external forces and causes less bowstringing. However the results of Schweizer have showed no significant differences between the forces achieved during the two grip positions.

As the subjects of this study are world class boulderers, they also respond to the given anthropometric description. Although our elite boulderers had similar anthropometric parameters to these of the elite sport climbers competing in the "difficulty" discipline tested by Watts et al. (8), slight differences still exist. The male and female boulderers from the present study have a higher percentage of body fat (21% and 73% difference respectively). The male boulderers also have 20% higher grip strength. These facts could be explained with the differences in the character of the two disciplines and the adaptations which the two types of exercise provoke. Sport climbing competition time is 3 - 10 minutes, while Bouldering is more intensive and usually lasts only seconds. Nevertheless compared to climbers with less ability, the world-class boulderers seem to have less percentage of body fat (5, 6, 19, 27, 28). The values of the height and body mass of the boulderers are smaller and their values of the grip strength are higher. Although the differences are not very big, the tendency can be observed in the presented results in Table 4.

The percentage of muscle mass of the tested boulder competitors could not be compared with values of other climbers, because of the lack of such data. It was less than the values of elite weight lifters and similar to these of elite wrestlers (31) and light-weight rowers investigated by Slater et al. (32). The authors concluded that the more successful rowers were those with lower body fat and greater total muscle mass. In another study with high altitude climbers, the summiteers appeared to have lower percentage of body fat and higher percentage of muscle mass than non-summiteers (33). A very high percentage of the muscle mass would raise the oxygen and energy consumption, which is not successful in high mountaineering. Most likely this variable must not exceed a certain level. It could be assumed that the strength nature of bouldering demands boulderers to be more muscular than other climbers. However a very high percentage of muscle mass is

Table 4. *Anthropometric variables and grip strength of elite and recreational climbers*

Study	Climbing ability	Gender	Age (years)	Height (cm)	Body mass (kg)	Body mass index	Body fat (%)	Grip strength (kg)	Grip strength to body weight ratio
Watts et al. 1993 ⁸	World Cup finalists (8b+/8c French grade)	male	23.9 ± 5.2 (n 7)	179.3 ± 5.2 (n 7)	62.4 ± 4.5 (n 7)		4.8 ± 2.3 ^d (n 7)	48.7 ± 9.1 ^a (n 7)	0.78 ± 0.13 ^a (n 7)
	World Cup finalists (8a+ French grade)	female	27.3 ± 1.9 (n 6)	162.3 ± 4.6 (n 6)	46.8 ± 4.9 (n 6)		9.6 ± 1.9 ^d (n 6)	30.3 ± 3.1 ^a (n 6)	0.65 ± 0.04 (n 6) ^a
Grant 1996 ⁵	Elite climbers (minimum E1 British ranking)	male	27.8 ± 7.2 (n 10)	178.9 ± 8.5 (n 10)	74.5 ± 9.6 (n 10)		14.0 ± 3.7 ^e (n 10)	54.25 ± 2.35 ^b (n 10)	
	Recreational climbers	male	32.0 ± 9.2 (n 10)	179.4 ± 7.9 (n 10)	72.9 ± 10.3 (n 10)		15.3 ± 3.0 ^e (n 10)	48.13 ± 2.35 ^b (n 10)	
Mermier et al. 2000 ⁶	Climbers of various skill level (5.6 - 5.13c Yosemite Decimal Scale)	male	30.4 ± 6.0 (n 24)	177.4 ± 8.8 (n 24)	72.8 ± 11.6 (n 24)		9.8 ± 3.5 ^d (n 24)		0.65 ± 0.14 ^c (n 24)
		female	32.2 ± 9.2 (n 20)	166.4 ± 5.7 (n 20)	60.1 ± 5.9 (n 20)		20.7 ± 4.9 ^d (n 20)		0.49 ± 0.1 ^c (n 20)
Sheel et al. 2003 ²⁹	5.12a - 5.14c French grade	male	19.3 ± 6.6 (n 6)	171.0 ± 5.3 (n 6)	65.9 ± 8.1 (n 6)	22.5 (n 6)	6.0 ± 0.9 (n 6)		
	5.12a - 5.12b French grade	female	16.0 ± 1.7 (n 3)	163.6 ± 8.9 (n 3)	54.7 ± 6.6 (n 3)	20.4 (n 3)	1.2 ± 0.3 (n 3)		
Schöffl et al. 2006 ²⁷	10- UIAA	male	26.6 (n 28)	R 165 - 193 (n 28)	68.5 (n 28)	21.38 (n 28)	6.2 (n 28)		
Michailov 2006 ¹⁹	Climbers of various skill level (6c - 8b + French grade)	male	28.1 ± 4.9 (n 17)	175.3 ± 7.5 (n 13)	68.8 ± 7.4 (n18)	21.2 ± 0.9 (n 13)	6.9 ± 1.4 ^d (n 11)		
Berrostegieta 2006 ³⁰	> 8c (French grade)	male		174 ± 6 (n 10)	64.5 ± 4.6 (n10)	21.31 (n10)	9.3 ± 0.7 ^f (n 10)		
España-Romero et al. ⁹	Elite and expert climbers (female 7a, male 8a French grade)	male	31.2 ± 5.7 (n 8)	172.7 ± 3.7 (n 8)	66.1 ± 4 (n 8)	22.2 ± 1.1 (n 8)	13.5 ± 3.7 ^g (n 8)	100.7 ± 9.2 ^a (n 8)	1.5 ± 0.1 ^a (n 8)
		female	28.6 ± 3.9 (n 8)	161.8 ± 2.8 (n 8)	53.0 ± 3.9 (n 8)	20.2 ± 1.1 (n 8)	26.0 ± 3 ^g (n 8)	65.4 ± 11.3 ^a (n 8)	1.2 ± 0.2 ^a (8)
Michailov, Mladenov, Schoeffl Present study	World-class competition boulderers	male	25.8 ± 5.1 (n 18)	174.6 ± 5.6 (n 18)	67.3 ± 6 (n 18)	22 ± 1.4 (n 18)	5.8 ± 1.8 (n 18)	58.6 ± 11.4 ^a (n14)	0.9 ± 0.2 ^a (n14)
		female	25.1 ± 5.3 (n 7)	162.6 ± 11.6 (n 7)	54 ± 6.8 (n 7)	20.4 ± 1.1 (n 7)	16.6 ± 3.6 (n 7)	28 ± 8.7 ^a (n 7)	0.5 ± 0.1 ^a (7)

^a Summed right and left side scores divided by two; ^b right hand scores; ^c scores of the dominant hand; ^d Jackson and Pollock's (1985) method; ^e Durnin and Womersley's (1974) method; ^f GREC method; ^g DXA method; Data reported are mean ± standard deviation

expected to reduce the relative strength. The muscle mass of boulderers should stay in an optimal diapason and muscle hypertrophy should occur in the specific, most responsible for the success muscle groups.

There is one more study, which has investigated the muscle mass of climbers with minimum level of 8c (French grade) but using GREC method (30). The percentage of muscle mass was 47.24 %, very similar to the present findings. Some of the subjects were performing at the limits of the human abilities in sport climbing. The climbing scene have demonstrated that such climbers show top performance in bouldering as well. This raises the questions: will there be a difference in this variable between specialized sport climbers and

boulderers and is total specialization in a given climbing discipline obligatory? Considering the results in Fig. 3 this common tendency in elite sport is partly taking place in competitive bouldering.

Many components have been proposed which correlate with the overall climbing performance (4). Nevertheless no study has yet cleared the ranks of all factors which lead to success. Moreover, the qualification of the tested climbers, different climbing disciplines, styles and terrains may change the relative contribution of the factors of performance, which increases the difficulty of a scientifically backed training model (1). However, some authors have proved the major importance of the specific strength endurance (assessed trough climbing

to exhaustion) in sport climbing with strong correlation coefficients (17, 19, 23, 27, 34). Climbers' maximal strength also correlates distinctly with climbing performance (19, 21). The correlation between isokinetic and isometric maximal strength led Schweizer and Furrer to use an isokinetic device for measuring climbers' forearm strength during concentric and eccentric motions by the performance of three movements: wrist flexion, rolling of a bar with fingers and flexion of the PIP joint (21). The correlation coefficients between the relative strength values and redpoint level have varied from $r = 0.31$ to $r = 0.57$. New knowledge on correlations between kinanthropometric characteristics and performance brought the study of España-Romero et al. (9). Arm mean length, arm to height ratio, forearm width and forearm lean mass and right hand length in men as well as body mass, body mass index and lean mass in women could be determinants of climbing performance.

The present study demonstrated that taller boulderers did not have an advantage in this bouldering competition but age and experience does reflect positively on the ranking. The non-significant correlation coefficients between the men's ranking in the World Cup in Sofia and the other variables demonstrated that performance depended on a summary effect of different factors as well as on the character of the boulder problems; which can have physical, technical and mental demands in different proportions. This explains the moderate correlations in between the rankings from the first World Cup in Erlangen and the second in Sofia. It can be assumed that the sports results are not stable.

Insignificant correlations between the competition performance, specific physical qualities, anthropometric parameters, technique and general fitness were also reported in a study of the Bulgarian Junior Competition Climbing Team (18). These findings confirm that high performance in competition climbing could be achieved through different combinations of the decisive factors and in dependence on the varying conditions at different competitions.

Anyhow the coefficients of variance of the height, body mass, body mass index and percentage of muscle mass presented the subjects in this study as a homogeneous group. According to the specific strength and specific relative strength, the group was relatively homogeneous. It can be concluded that in order to compete on a World Cup level, boulder climbers should correspond to the collected data.

Regretfully, most measured variables do not influence significantly the different types of outdoor achievements. This is probably due to the fact that some of the competitors are climbing mostly on artificial structures and haven't realized their world-class abilities on real rock surfaces. However the specific

strength of the male competitors appears to be very important in outdoor bouldering, where the tactics should be a less potent factor because the most difficult grades are only generally climbed successfully after a great number of attempts. This could be the reason for the establishment of a partial hierarchical structure of performance in the redpoint style in another study with Bulgarian sport climbers (19) (Fig. 5).

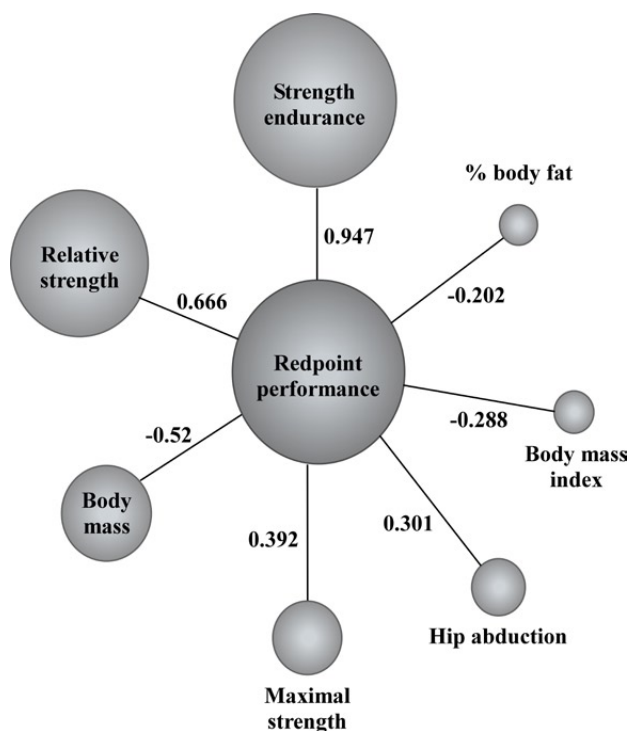


Fig. 5. Correlations between the redpoint achievements and some of the factors of performance, Michailov (2006)

Conclusion

With small differences, elite boulderers showed similar characteristics as elite sport climbers. Nevertheless boulderers do have a higher percentage of body fat and greater strength measured via hand dynamometer (males). The specific strength and relative strength appear to be important factors for outdoor bouldering performance, but success in competition depends on the summary effect of the decisive factors, including unstudied mental factors. Performance was not stable at different stages of the World Cup due to the varying conditions in the different competitions. Further research is necessary to fully understand the performance determining factors in bouldering.

Acknowledgments

The authors would like to thank all competitors who took part in the study. We would also like to thank to the chief judge Evgeny Levin and to the organizer (Bulgarian Climbing and Mountaineering Federation) of the 2007 Bouldering World Cup in Sofia for their understanding and support, which let us implement the measurements.

References

1. Michailov ML. Evolvement and experimentation of a new interval method for strength endurance development. In: Moritz FE, Haake S, ed. *The Engineering of Sport 6*, Volume 2. Development for disciplines. New York: Springer Science and Business Media; 2006: 291-6.
2. Morrison AB, Schöffl VR. Physiological responses to rock climbing in young climbers. *Br J Sports Med* 2007; 41: 852-61.
3. Sheel AW. Physiology of sport rock climbing. *Br J Sports Med* 2004; 38: 355-9.
4. Watts PB. Physiology of difficult rock climbing. *Eur J Appl Physiol* 2004; 91: 361-72.
5. Grant S, Hynes V, Whittaker A, Aitchison T. Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. *J Sports Sci* 1996; 14: 301-9.
6. Mermier C, Janot J, Parker D, Swan J. Physiological and anthropometric determinants of sport climbing performance. *Br J Sports Med* 2000; 34: 359-66.
7. Watts PB. Anthropometry of young competitive sport rock climbers. *Br J Sports Med* 2003; 37: 420-4.
8. Watts PB, Martin D, Durtschi S. Anthropometric profiles of elite male and female sport rock climbers. *J of Sports Sciences* 1993; 11: 113-7.
9. España-Romero V, Francisco B, Porcel O, et al. Climbing time to exhaustion is a determinant of climbing performance in high-level sport climbers. *Eur J Appl Physiol* 2009; 107 (5): 517-25.
10. Hochholzer T, Schöffl VR. *One move too many*. 2nd ed. Ebenhausen: Lochner-verlag; 2006.
11. Josephsen G, Shinneman S, Tamayo-Sarver J, et al. Injuries in bouldering: a prospective study. *Wilderness Environ Med* 2007; 18: 271-80.
12. Heyward VH, Stolarczyk LM. *Applied body composition assessment*. Champaign: Human Kinetics; 1996.
13. Lee RC, Wang Z, Heo M, et al. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 2000; 72: 796-803.
14. Köstermeyer G, Weineck J. Necessity of one-finger-training for the increase of performance in climbing. Comparison of force development between one- and four-finger maximum contraction. *D Z Sportmed* 1995; 46:356-62.
15. Schöffl VR, Einwag F, Strecker W, Schöffl I. Strength Measurement after conservatively treated Pulley Ruptures in Climbers. *Med Sci Sport Exerc* 2006; 38(4):637-43.
16. Schweizer A. Biomechanical properties of the crimp grip position in rock climbers. *Journal of Biomechanics* 2001; 34: 217-223.
17. Binney DM, Cochrane T. Identification of selected attributes, which significantly predict competition climbing performance in competitive rock climbing. *J Sports Sci* 1999; 17(1): 11-2.
18. Michailov ML. Anthropometric and sport specific indicators of elite climbing competitors (boys and girls). In: Davidov D (eds). *Scientific conference of young sport researchers*. Sofia: Tiptoppress; 2005: 169-76.
19. Michailov ML. Study of some of the major factors of performance in climbing. *Sport & Science* 2006, special edition; 2: 11-20.
20. Wall CB, Starek JE, Fleck SJ, Byrnes WC. Prediction of indoor climbing performance in women rock climbing. *J Strength Cond Res* 2004; 18(1):77-83.
21. Schweizer A, Furrer M. Correlation of forearm strength and sport climbing performance. *Isokinetics and Exercise Science* 2007; 15: 211-6.
22. Neykov S. *Training of elite rowers in the macro cycle*. 1th ed. Sofia: Tiptoppress; 2007.
23. Schöffl VR, Hochholzer T, Imhoff A, Schöffl I. Radiographic Adaptations to the Stress of High Level Rock Climbing in Junior Athletes: A-5 Year Longitudinal Study of the German Junior National Team and a Group of Recreational Climbers. *Am J Sports Med* 2006; 35(1): 86-92.
24. Ferguson RA, Brown MD. Arterial blood pressure and forearm vascular conductance responses to sustained and rhythmic isometric exercise and arterial occlusion in trained rock climbers and untrained sedentary subjects. *Eur J Appl Physiol Occup Physiol* 1997; 76(2): 174-80.
25. MacLeod D, Sutherland DL, Buntin L et al. Physiological determinants of climbing specific finger endurance and sport rock climbing performance. *J Sports Sc.* 2007; 25(12):1433-43.
26. Quaine F, Vigouroux L. Maximal resultant four fingertip force and fatigue of the extrinsic muscles of the hand in different sport climbing finger grips. *Int J Sports Med* 2004; 25:634-37.
27. Schöffl VR, Möckel M, Köstermeyer G, et al. Development of a performance diagnosis of the anaerobic strength endurance of the forearm flexor muscles in sport climbing. *Int J Sports Med* 2006; 27: 205-211.
28. Schöffl VR, Klee S, Strecker W. Evaluation of physiological standard pressures of the forearm flexor muscles during sport specific ergometry in sport climbers. *Br J Sports Med* 2004; 38(4): 422-5.
29. Sheel AW, Seddon N, Knight A, et al. Physiological responses to indoor rock climbing and their relationship to maximal cycle ergometry. *Med Sci Sports Exerc* 2003; 35: 1225-31.
30. Berrostegetia JL. Relation between specific force tests and chained degree in high level sport climbers. In: Moritz EF, Haake S, ed. *The engineering of Sport 6*, Volume 2. Developments for disciplines. New York Springer Science and Business Media; 2006.
31. Slanchev P. *Sports Medicine*. Sofia: Novi Znanian; 1998.
32. Slater GJ, Rice AJ, Mujika I, et al. Physique traits of lightweight rowers and their relationship to competitive success. *Br J Sports Med* 2005; 39: 736-41.
33. Mladenov VL, Michailov M. Characteristics of high altitude climbers and the influence of an expedition on the anthropometric variables. *Sport & Science* 2007, special edition; 4: 83-90.
34. Koesteremeyer G. Strength endurance training for climbers. Proceedings of the BMC International High Performance Seminar; 2000 May 08-12; Plas y Brenin National Mountain Centre, North Wales.

Received: September 26, 2009

Accepted: December 02, 2009

Published: December 08, 2009

Address for correspondence:

Michail Michailov

Department Theory of Sports Training,

National Sports Academy,

Sofia,

Bulgaria

Tel. +359 2 8683684

Mobile +359 889227685

Email: michailovi@hotmail.com

Fax +359 2 9621263

Michail L. Michailov: michailovi@hotmail.com

Lubomir V. Mladenov: lubomladenov@abv.bg

Volker R. Schöffl: volker.schoeffl@sozialstiftung-bamberg.de