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Evaluation of the level of anaerobic power and its effect on speed climbing performance in elite climbers

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Abstract
Speed climbing is the most dynamic discipline among all climbing sports. Previous studies have emphasized the combined strength and speed character of speed climbing (determined by high level of anaerobic power of the muscles). The main aim of this study was to evaluate the level of mechanical power of the muscles generated during specific climbing movements in competition speed climbing at the level of the final rounds of the IFSC World Cup. The material for the study was provided by the somatic data and scores obtained by six speed climbers who regularly participated in speed climbing events during the IFSC World Cup. The analyses were performed based on the results derived from the IFSC World Cup played on 7 to 8 May 2016 in Nankin, China. The findings of this study lead to the following conclusions: Development of the level of relative anaerobic power in speed climbers represents the basis for the training process. The Margaria–Kalamen formula is likely to represent a valuable tool for evaluation of the level of sport-specific power in speed climbing. One of the determinants of high sport-specific power in speed climbing is high level of technical skills. The values of sport-specific power parameters can be useful in recruitment of athletes in speed climbing.

KEYWORDS: speed climbing, muscle power, anaerobic power.

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Introduction

Contemporary sports can be divided into those with the endurance character of motor activities (long--term exercise), sports with strength and speed character (exercise with very high intensity and short duration) and mixed sports, where the exercise is of both speed and mixed strength and speed character (e.g. team sports) [29].

As a sport, climbing includes three disciplines which differ depending on motor demands: speed climbing, bouldering and lead climbing. Lead climbing is mostly categorized by theorists and practitioners of climbing as a mixed endurance and strength sport [27, 31]. Bouldering requires a high level of strength (maximal strength), ability to dynamically develop force and efficient and quick recovery after an intensive exercise [8, 23]. Speed climbing is the most dynamic discipline among all climbing sports. Previous studies have emphasized the combined strength and speed character of speed climbing (determined by high level of anaerobic power of the muscles) [14, 15, 16].

In the final rounds of the IFSC World Cup, elite speed climbers achieve climbing times ranging from 5.9 to 6.3 s[1]. Speed climbing requires quick movements of the whole body in a specific space, which is substantially determined by the high level of anaerobic power. Muscle power is defined as an ability to develop high forces of muscle contraction over a short period of time [3]. The high level of anaerobic muscle power is determined by: muscle fibre ratio (high level of power is connected with greater content of fast-twitch fibres) and bioenergy abilities of human body [5, 11]. The main source of ATP resynthesis needed for muscle work during supramaximal exercise of up to 5 seconds is phosphocreatine (PCr) [6], which accounts for ca. 70% of this source [25]. If the exercise is extended over 5 seconds, the importance of anaerobic glycolysis increases, with decreasing contribution of the mechanism of energy generation from CP [25]. Therefore, speed climbing at elite level represents a supramaximal-intensity exercise, with ATP resynthesis ensured mostly by phosphagen systems and less by anaerobic glycolysis. However, it should be emphasized that the important factor that affects the level of locomotor speed is well-developed technique of sport-specific movements [11]. Greater technical skill level helps improve the movement speed. In high-speed sports, technique ensures development of maximal (or optimal) speed of a specific movement [28]. This leads to the assumption that quick moving over a climbing route requires a high level of anaerobic power generated during climbing-specific movements. Therefore, a sport-specific power is essential in speed climbing. The question arises about the level of power generated during a competition speed climbing. The analysis of the scientific literature on speed sports climbing reveals the lack of studies documented in this area. The tests used to date in scientific studies concerning speed climbing were based on non-specific movements [14, 15, 16]. The only study that has attempted to utilize measurements during a speed climbing race was written by Fuss and Niegl [10]. Among other things, the study analysed time of contact with the climbing hold, level of contact force and climbing speed between two holds. The important question that should be asked is how the sport-specific power can be examined in speed climbing. In this climbing discipline, the athlete must move their body over the distance of 15 metres in shortest time possible and additionally overcome the gravity force. Consequently, it seems that the Margaria–Kalamen [20] formula may offer a valuable tool for evaluation of sport-specific power in speed climbing. This test is to defeat 9 stairs in the shortest possible time after the 6-meter run. The power is calculated based on the speed of distance travel and body weight. Power is calculated on the basis of the formula: P (power) = body weight × gravity × vertical height between 3 and 9 step / time needed to overcome the steps [1, 36]. In this test, the participant moves up (up the stairs) as do the climbers in speed climbing. The power that the climber develops while running is conditioned by the same variables that determine the value of power in Margaria's–Kalamen test.

Aim of Study

The main aim of this study was to evaluate the level of mechanical power of the muscles generated during specific climbing movements in competition speed climbing at level of the final rounds of the IFSC World Cup. Furthermore, the study attempts to identify the relationships between the level of anaerobic muscle power in climbers with the competitive climbing performance and to provide more insight into this field of research through quantitative description of the character and strength of correlations between the variables. This goal leads to the following research questions:

1. Is there and what is the character of the correlations between competitive climbing performance in speed climbing and the analysed characteristics and somatic indices?
2. What is the level of sport-specific power in speed climbing and what is the strength of correlations with the competitive climbing performance?

Material and Methods

The material for the study was provided by the somatic data and scores obtained by six speed climbers who regularly participated in speed climbing events during

[1] The time range is generalized and the detailed data can be found on the official website of the IFSC internet websites (http://www.ifsc-climbing.org).

the IFSC World Cup. The analyses were performed based on the results derived from the IFSC World Cup played on 7 to 8 May 2016 in Nankin, China. The athletes examined in the study were those who were placed second to sixth and eighth in the tournament. The data were collected based on the analysis of video recordings for final rounds of the tournament. The V1 Home ver. 2.0 Basic software was used for the purpose. The results of individual climbing races obtained by the athletes were used in the study. The following variables connected with the time of a climbing race were evaluated based on the video analysis:

- the best individual climbing time T_{min} (s) – time of the fastest race for the athlete;
- start reaction time in the fastest climbing race RT T_{min} (s) – the time between the starting signal and starting the race[2];
- the proper time of the fastest climbing race T_{min} – RT (s) after subtraction of the time obtained in the fastest race from starting reaction time;
- mean time for all the climbing races $_{avg}T$ (s);
- mean time for all starting reaction times $_{avg}RT$ (s);
- mean time of all the climbing races after subtraction of starting reaction times $_{avg}T - _{avg}RT$ (s);

In the next step of the analysis, based on the value of the proper times, we calculated the parameters of mechanical power generated by the muscles during a speed climbing race. The Margaria–Kalamen formula was used [20]. The following relative parameters were calculated in absolute and relative (calculated per body mass of the climber) terms:

- $P_{Tmin - RT}$ (W) and (W/kg), i.e. power generated during the fastest climbing race,
 and
- $P_{avgT - avgRT}$ (W) and (W/kg), i.e. mean power for all the races during the tournament.

With regards to the morphological body build of climbers, the data on body height (BH) and body mass (BM) were derived from the official website of the International Federation of Sport Climbing [3]. These data were used to calculate the BMI index, ponderal index and the Rohrer's index for each athlete [26].

The statistical analysis of the data collected in the study used the following calculations:

1. The basic descriptive statistics (arithmetic mean, standard deviation, median, 25th percentile, 75th percentile, minimal and maximal value and coefficient of variation for each variable);
2. The Kolmogorov–Smirnov test was conducted to evaluate the consistency of the distribution of variables with normal distribution;
3. The Pearson's linear correlation was used and the correlation coefficients $r_{(x,y)}$ were calculated to evaluate strength and direction of the relationships between the best time obtained by climbers during the tournament (T_{min}) and other variables. The evaluation of the correlation strength was based on the classification proposed by Ferguson [9].
4. Simple regression equations were formulated to examine the relationships between the best climbing time during the climbing tournament (T_{min}) and variables that showed the strongest correlation: $y = ax + b$, where y means the response variable (time of the fastest race, T_{min}), and x is the explanatory variable [33, 34].

The collected data were developed using the STATISTICA 8 software package (StatSoft®). The graphical representation of the results was prepared using the Microsoft® Excel software from the Office 2007 package.

Results

The results of the evaluation of the somatic characteristics, anthropological indices, values of variables that describe race times and power parameters were presented in Table 1. These data can be used to conclude that the group of the athletes was strongly homogeneous in terms of the characteristics studied. Relatively high differences were found for body mass (BM), which consequently translated into the results obtained for the best race ($P_{Tmin - RT}$ [W]) and mean power in all the races ($P_{avgT - avgRT}$ [W]). Calculation of the power parameters per body mass showed that the group of athletes studied is homogeneous. The range of variability for $P_{Tmin - RT}$ [W/kg] was 24.57 ÷ 26.96, which results in 2.39 [W/kg] of the interquartile range. Furthermore, the same parameters of the statistical description for $P_{avgT - avgRT}$ [W/kg] were: 23.11 ÷ 26.08, which translates into 2.97 [W/kg] of the range. Mean reaction time $_{avg}RT$ [s] in the group of climbers was also a variable with low intraclass variation. The range for the parameter $_{avg}RT$ [s] of 0.05 [s] was also demonstrated by the values of the coefficient of variation and standard deviation. Furthermore, reaction time in the fastest race differentiated climbers the most (with the range of 0.12 [s]) and the coefficient of variation of 11.66%). On the average, the fastest race time (T_{min}) was 6.05 [s]. The statistical average of time of all the races ($_{avg}T$) was 6.24 [s]. After subtraction of reaction times (RT) from this value, the climbing times

[2] The climbing race started at the moment when the lower limb had not physical contact with the starting platform.
[3] http://www.ifsc-climbing.org

Table 1. Statistical characteristics of somatic variables, temporal parameters and anaerobic power in the athletes studied

	x	sd	V%	min	25	75	max
BH [cm]	179.33	9.52	5.31	166.00	173.00	187.00	190.00
BM [kg]	72.17	7.31	10.12	64.00	66.25	77.75	81.00
BMI	22.41	0.77	3.43	21.31	21.87	22.87	23.23
index of slenderness	43.09	1.03	2.40	41.50	42.57	43.53	44.47
Rohrer's index	1.25	0.09	7.32	1.14	1.21	1.30	1.40
$_{avg}RT$ [s]	0.41	0.023	5.687	0.380	0.388	0.428	0.430
$_{avg}T$ [s]	6.242	0.274	4.393	6.055	6.115	6.210	6.789
$_{avg}T - RT$ [s]	5.833	0.268	4.596	5.642	5.706	5.792	6.369
RT T_{min} [s]	0.42	0.05	11.66	0.36	0.40	0.46	0.48
T_{min} [s]	6.054	0.220	3.630	5.858	5.922	6.070	6.469
$T_{min} - RT$ [s]	5.626	0.201	3.574	5.458	5.481	5.670	5.989
$P_{Tmin-RT}$ [W]	1890.03	207.17	10.96	1621.62	1741.90	2017.70	2166.72
$P_{Tmin-RT}$ [W/kg]	26.18	0.91	3.46	24.57	25.95	26.85	26.96
$P_{avgT-RT}$ [W]	1826.88	232.85	12.75	1524.99	1664.11	1994.69	2112.70
$P_{avgT-avgRT}$ [W/kg]	25.27	1.09	4.31	23.11	25.41	25.79	26.08

(T_{min} – RT and $_{avg}T - _{avg}RT$) were lower than 6 seconds. The level of variation in terms of racing times was low in all the cases.

Table 2 contains the results of the analysis of the Pearson correlation coefficient. These results lead to the conclusion that the highest strength of the correlation with T_{min} was observed for $P_{Tmin-RT}$ [W/kg] and $P_{avgT-avgRT}$ [W/kg], which

Table 2. Values of Pearson correlation coefficients between the time of the fastest race and the somatic variables, temporal parameters and parameters of anaerobic power

$r_{x,y}$	T_{min} [s]
BH [cm]	0.04
BM [kg]	–0.23
BMI	–0.80
Ponderal index	0.42
Rohrer's index	–0.42
RT T_{min} [s]	0.57
$_{avg}RT$ [s]	–0.12
$P_{Tmin-RT}$ [W]	–0.50
$P_{Tmin-RT}$ [W/kg]	**–0.98***
$P_{avgT-RT}$ [W]	–0.47
$P_{avgT-avgRT}$ [W/kg]	**–0.90***

* Statistically significant correlations at the level of $p < 0.05$

Table 3. Values of regression model (with regression summary) where the explanatory variable is represented by the relative power in the fastest race $P_{Tmin-RT}$

	intercept	$P_{Tmin-RT}$ [W/kg]
Beta		–0.982200
std. err. of beta		0.093919
B	12.28852	–0.23811
std. err. of beta	0.596432	0.022768
t(4)	20.6034	–10.4580
p-level	0.000033	0.000472
regression summary		
multiple R	0.9822	
multiple R^2	0.9647	
adjusted R^2	0.9559	
F(1,4)	109.3693	
p-value	0.0005	
std. err. of estimate	0.0462	

were statistically significant. The high level of correlation was also found for BMI while slightly weaker values were documented for the index of slenderness and the Rohrer's index, RT T_{min}, $P_{Tmin-RT}$ [W] and $P_{avgT-avgRT}$ [W]. These correlations were not statistically significant.

Simple linear regression models were designed to examine the observed relationships. This analysis was conducted only for the variables with the highest and statistically significant correlations with the value of the parameter T_{min} [s]. Table 3 presents the data concerning the regression model where the explanatory variable is represented by the relative power in the fastest race $P_{Tmin-RT}$. The increase in power parameter by 1 [W/kg] leads to the time reduction by 0.238 [s]. The value of the coefficient of determination R^2 was 0.964, which means that the model with the independent variable $P_{Tmin-RT}$ [W/kg] explains over 96% of the variance for T_{min} [s] and is statistically significant.

Table 4 shows the data concerning the regression model with the independent variable being the parameter $P_{avgT-avgRT}$ [W/kg]. The calculated values of the parameters provide information that the increase in the value of this parameter by 1 unit leads to the decline in T_{min} [s] by 0.1816. The equation is statistically significant, with the coefficient R^2 of 0.808.

Table 4. Values of regression model (with regression summary) where the explanatory variable being the parameter $P_{avgT-avgRT}$ [W/kg]

	intercept	$P_{avgT-avgRT}$ [W/kg]
Beta		–0.899186
std. err. of beta		0.218783
B	10.64367	–0.18162
std. err. of B	1.117548	0.044191
t(4)	9.52413	–4.10993
p-level	0.000679	0.014733
regression summary		
multiple R	0.89919	
multiple R^2	0.80854	
adjusted R^2	0.76067	
F(1,4)	16.89156	
p-value	0.01473	
std. err. of estimate	0.10752	

Discussion

The objective in speed climbing is to climb the 15 meter distance in the shortest possible time. The race occurs in vertical direction using the climbing holds and footholds fixed to a slightly overhang wall (five degrees). Two standard routes (with the same distances between handholds and footholds and their number) are used during tournaments. The athletes attempt to climb up as fast as possible, which leads to a substantial external load. Furthermore, despite standardization, the unique system of holds requires performing many complex movements over the race. This general characterization of speed climbing reveals certain motor requirements of this climbing discipline. These requirements allow for classification of this climbing discipline in terms of motor potential that guarantees successful competitive performance.

Sozański et al. [28] attempted to classify sports according to speed requirements. In this of classification, one of the groups included the sports which require maximal values of the most speed components in relatively standard situations (a group of running sprints, speed skating, hurdle races) and those which require a maximal or close-to-maximal values of velocity components under conditions of a substantial external load or complex movements in relatively standard situations (e.g. artistic gymnastics, shot put). In light of the characteristics of speed climbing and the above classification, it seems that the sport can be classified somewhere between these two groups since it requires maximal values of velocity components (reaction time, movement frequency, simple movement time) under conditions of the substantial load (moving the body in the vertical direction) and in movements with complex coordination (varied arrangement of holds) in relatively standard situations.

The analysis concerned the basic characteristics of the somatic build and certain indices of body weight and height. In a study by Krawczyk and Ozimek [14], mean body mass of Polish climbers was 67.18 kg, with climbers defined as those who participated in speed climbing tournaments. The analysis of only four best competitors in the Polish Cup showed that their mean level of body mass was 66.73 kg [16]. The mean body mass in the IFSC World Cup was 72.17 kg. The noticeable difference between Polish competitors and world elite athletes is likely to result from greater mean body heights at the elite climbers (179.33 cm vs. 174 cm) and, consequently, bigger bodies (taller climbers are mainly characterized by greater body mass [31]).

Comparison of mean body height and mean body mass in the analysed speed climbers with the elite climbers who participate in other climbing disciplines [7, 21, 24, 32] shows in general a similar body height and higher body mass in speed climbers. Higher body mass compared to climbers who compete in other climbing disciplines may be linked to a higher levels of active tissue and can consequently lead to higher skeletal muscle mass, which represents around 43% of the mass of adult human [4]. As demonstrated by e.g. Gabryś et al. [11] and Bompa and Haff [2] higher level of muscle mass is a critical factor to affect the ability to generate greater power. Based on the analysis of standard deviation and the coefficient of variation, one can conclude that in terms of body height and body mass, the study group presented a relatively noticeable level of variation (higher in the case of body mass). This is supported by the results obtained for the minimum–maximum fluctuation scale. High variation of these somatic characteristics may suggest that in elite speed climbing competitors, they may not be of much importance, especially if they are analysed individually. Correlation analysis of coexistence of these both characteristics with the race results supports this notion. Value of the $r_{x,y}$ coefficient for body height was 0.04, whereas for body mass, this value was –0.23. The results of correlation analysis point to an insignificant correlation between low body mass (or lower body mass) for higher race times. This differs from the conclusions presented in previous reports which have suggested a rather low level of body mass as a specific handicap to a climber that is conductive to the achievement of high competitive performance [12, 20, 21, 31]. However, the results of these analyses have mainly concerned bouldering and lead climbing. The present study lacks the data on the level of fat tissue, but it is commonly known that high sport skill level is achieved by players with low fat percentage and it can be assumed that the athletes studied were characterized by an insignificant fat percentage compared to total body mass. Therefore, the lean body mass seems to be required, or, more likely, skeletal muscle mass (especially of type II muscle fibres), whose hypertrophy improves the ability to develop strength and power [2] and leads to body mass gains (which must be kept low in order to maintain a specific level of relative power).

In a study of participants of the World Cup in bouldering, the BMI index was 22 [21]. Macdonald and Callender [18], who analysed boulderers, documented BMI index of 22.3. España-Romero et al. [7] found that the BMI index was 21.7 among elite lead climbers (with sport skill level of 8b OS). Furthermore, Watts et al. [32] examined a group of lead climbers who were finalist of the World Cup and found this index to be at the level of 19.41, which is much lower than the above mentioned indices (this value was calculated for the purposes of our own research since Watts et al. did not present the data concerning BMI). In a study by Magiera et al. [19], BMI was 21.82 (sport skill level of 7a-8a climbers). Value of BMI indices in speed climbing examined by Krawczyk and Ozimek [14] was 22.11. Furthermore, the level of this index in the present study, which focused on speed climbers, was 22.41.

Similar level of body height in representatives of all climbing disciplines indicates that the differences in the value of BMI indices may be determined by kinetics of body mass development. Assuming that elite sport climbers are characterized by a low fat percentage [14, 21, 31], body mass level in the climbers studied will be determined mainly by the development of lean body mass, and, most likely, by the development of skeletal muscle mass. As emphasized by Łaska-Mierzejewska [17], BMI index in athletes represents a measure of the development of the active tissue. Therefore, in this case, this measure can be considered as an index of lean body mass (active tissue), with skeletal muscles being one of its components. As mentioned before, they account for 43% of human body mass. Consequently, lower values of BMI indices in lead climbers may be explained by the endurance character of this sport. It is generally accepted that type S muscle fibres, with insignificant diameters, are of essential importance in endurance sports [22]. The level of BMI indices differ in bouldering, which requires a high level of maximal strength, power [21, 35] and resistance to fatigue during an intensive exercise [23], may show a different pattern. In this climbing discipline, high level of the type IIA muscle fibres (with greater diameters than in the type S fibres) is needed to reach a high level of sports achievement [4]). In speed climbing, BMI indices were the lowest, which shows that in terms of the level of active tissue, speed climbers demonstrate the highest level of development among all elite climbers. The speed character of speed climbing leads to the conclusion that high content of type IIA muscle fibres, with greater diameters (which can explain the higher body mass and greater BMI indices), is a key determinant of high level of competitive performance.

Furthermore, the present study showed that BMI indices are substantially correlated ($r_{(x,y)} = –0,80$) with the parameter T_{min}, which means that it can be treated as a more diagnostic measure than body mass or body height (results of correlations were statistically insignificant). The level of BMI results from mutual relation of the level of body height and body mass and, consequently, is the component of two somatic variables which, if analysed individually, did not show a high diagnostic value. The above observations lead to the conclusion that the recruitment, selection and the whole training process in speed climbing should take into consideration the orientation towards maintaining of adequate ratio of components which affect athlete's body mass. In the context of the present analysis, it can be adopted that training strategies based on maximization of the level of active tissue (including skeletal body mass) with simultaneous reduction in fat tissue may be recommended over the training process in speed climbing. The lack of statistical significance of the correlation between the BMI and climbing times and a relatively high level of its generalization limits the more definite reasoning. It also suggests the directions of further scientific research that is needed in this area.

The ponderal index and the Rohrer's index used for the purposes of this study did not show as clear correlations with T_{min} as the level of BMI indices. However, the emphasis should be on a relatively strong correlation of both indices ($r_{(x,y)} = 0.42$ and $r_{(x,y)} = –042$, respectively). The results suggest that the athletes with more slender bodies have greater opportunities for achievement of shorter times in speed climbing races. In light of the literature analysis, there have been few reports concerning the relationships between the two anthropological indices and scores in speed climbing.

One of the factors that determine locomotor speed is reaction time, which is defined as a time from the onset of the stimulus to initiation of motor activity [13]. This study attempted to evaluate starting reaction time in climbers. The V1 Home software was used for the purpose to make analysis of video recordings from the tournaments. Mean reaction time RT T_{min} in the fastest race was 0.420 s. Statistically average reaction time for all races $_{avg}$RT was 0.410 s. Therefore, the values were similar. Compared to track and field athletes, with their reaction times ranging from 0.105 to 0.150 s [30], the times obtained by climbers were noticeably longer. The difference is likely to have been caused by a different direction of athlete's motion. In a running sprint, start from the starting blocks occurs in the forward direction, which limits the effect of the gravity force. In a climbing sprint, the athlete has to overcome their body weight and the gravity force since the motion is performed upwards, leading to the delay in the moment of starting. Reaction time in running sprints has a insignificant effect on the final score (around 1 to 2%) in a 100 m run [30]. However, in speed climbing, the reaction time may be more significant since in light of our study, it is noticeably correlated with the final time ($r_{(x,y)} = 0.57$). This correlation was not statistically significant. Although these results show that shortening of reaction time in speed climbing may have a significant effect on the final result in the climbing race, in light of the statistical analysis, the conclusions should be drawn very carefully. The need for further research in this field to verify the results of the present study should be also emphasized.

The main aim of our own study was to determine the level of anaerobic power during a climbing race. We used the formula developed by Margaria–Kalamen et al. [20], based on the somatic data and information about times achieved by individual athletes. Based on the scientific literature review concerning climbing, one should emphasize that no previous analyses have been performed. In this study, the aim was achieved through the analysis of the two parameters: $P_{Tmin-RT}$ and $P_{avgT-RT}$. The first of them can be treated as an index that provides information about maximal abilities in terms of overcoming the external resistance and the top speed of muscle contraction in sport-specific movements in speed climbing. Therefore, a specific type of maximal power in a climbing race should be emphasized. The latter ($P_{avgT-RT}$), as a component of several climbing races, performed at relatively short time intervals (e.g. during one tournament or one training session) can be considered to be an indicator of the sport skill level. Based on the value of this index, the attempt can be made to determine the level of fitness and technical preparation of an athlete who participates in the competition.

Analysis of mean values and other parameters of descriptive statistics concerning power of the fastest race and mean value of power for all the races during the tournament reveals a very low variation of the group studied. Higher level of dispersion was found for $P_{Tmin-RT}$ and $P_{avgT-RT}$ expressed in absolute units. Dispersion of these parameters is likely to have an effect on the level of variation of the body mass which represents the component of the Margaria–Kalamen formula used in our own study. In light of the results of the correlation coefficient, the parameters $P_{Tmin-RT}$ [W] and $P_{avgT-RT}$ [W] also showed a moderate relationship with T_{min}. The same power parameters expressed in relative terms were more substantially correlated with the climbing time. Strength and directions of correlation between T_{min} and $P_{Tmin-RT}$ [W/kg] and $P_{avgT-RT}$ [W/kg] were $r_{(x,y)} = –0.98$ and $r_{(x,y)} = –0.90$. Both values of the calculated correlation coefficients were statistically significant. Furthermore, a low level of variation of relative sport-specific anaerobic power in the climbers analysed in the study may substantially support the notion of the importance of this parameter to the achievement of high performance in speed climbers. Arithmetic means, minimal and maximal values and quartiles that describe sport-specific power can be interpreted as models for this sport. In the training process, these data can be used as a criterion for selection of this competition at the level of adult athletes.

The results of the present study lead to the conclusion that the prerequisite for the effective performance during tournaments at elite level is achievement of adequate high level of sport-specific power. Furthermore, these results show that the level of relative sport-specific anaerobic power can be the factor that affects the level of achievement during speed climbing competition.

Another stage of the statistical analyses conducted in the study was to develop a simple regression model for each variable that describe relative anaerobic power of climbers. It was found that the model of regression with the parameter $P_{Tmin-RT}$ [W/kg] represents a more diagnostic tool than the model with the parameter $P_{avgT-RT}$ [W/kg]. The results of these analyses show unequivocally that the increase in the level of sport-specific anaerobic power relative to body mass is a factor that helps improve the climbing times. However, it should be emphasized that the climbing speed reached by the athletes depended not only on the anaerobic power but also on the high level of technical skills, which undoubtedly had and effect on the level of power generated during a race.

This study analysed a complex body motion of a climber. Therefore the power achieved by athletes was the net sport-specific power of upper and lower limbs. The mean value of power during the race in the climbers analysed in the study was around 25-26 [W/kg]. The question arises of what part of this value is generated by the upper limbs and which part is generated by the lower limbs. This question sets the objectives for further research in this field. However, it can be expected that the lower limbs have a greater effect on the development of this ability (due to the greater level of muscle mass in lower limbs) and, consequently, the development of the final result in a race. This fact has been emphasized before [3].

Furthermore, certain methodological limitations concerning this study should be emphasized. The results presented in the study used the data for the basic characteristics of the somatic built derived from the IFSC website. No direct body height and body mass measurements were made. Consequently, the results obtained in the study may differ from real ones. It appears to be clear that this leads to difficulties in reasoning, pointing to the need of renewed scientific verification of the analyses.

It should be noted that the video analysis was conducted based on the video recordings available in public IFSC websites and on Youtube. Furthermore, the analyses also used the V1 Home Basic freeware. One limitation to the analyses of video recordings was the frame rate (the film was recorded at the speed of 25 FPS). Consequently, it turned out that the real time of 1 FPS was 0.04 s. The values of power calculated based on this assumption lead to certain errors. This allowed for precise specification of the value of power and reaction times. This points clearly to the need for scientific verification of the results obtained in this study using more accurate tools. On the other hand, one advantage is that the financial costs of using such tools are very low. The method of using them, which was presented in this study, is likely to be very useful and valuable to everyday working during training under condition of climbing walls.

Conclusions

The findings of this study lead to the following conclusions:

1. Development of the level of relative anaerobic power in speed climbers represents the basis for the training process.
2. The Margaria–Kalamen formula is likely to represent a valuable tool for evaluation of the level of sport-specific power in speed climbing.
3. One of the determinants of high sport-specific power in speed climbing is high level of technical skills.
4. The values of sport-specific power parameters can be useful in recruitment of athletes in speed climbing.

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