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WORKLOAD CHARACTERISTIC, PERFORMANCE LIMITING FACTORS AND METHODS FOR STRENGTH AND ENDURANCE TRAINING IN ROCK CLIMBING*

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Abstract

In order to outline the performance limiting factors and to conduct an effective training process in rock climbing a characteristic of the physical activity is needed. On this basis proper training exercises and methods could be designed. Rock climbing has a variable character of the workload, includes many sub disciplines and demands complex development of the motor abilities. Different types of climbing vary in intensity, duration, methods used for protection and terrain. This may set different physical, mental and technical demands and may induce different physiological responses. Nevertheless, the performance limiting factors and training methods may be considered identical. Only the levels and proportions of development of the decisive abilities would be different.

A very important characteristic of the workload in climbing is that more than one third of the ascent time is spend in immobilized positions. Climbing involves also sustained intermittent isometric contractions. These characteristics largely explain the nonstandard physiological responses. One unique physiological response is that heart rate disproportionally rises in comparison to oxygen consumption and heart rate could not be used for training guidance.

Among the main training goals in rock climbing are: sport-specific strength and strength endurance of the forearm flexors, explosive strength of the arm flexors, strength endurance of the shoulder girdle and core maximal strength. Sport-specific strength is commonly developed through bouldering, hanging on fingerboards, exercising on campus boards and system training. Bouldering as a sport-specific exercise is highly effective for developing strength in unity with sports technique. However, the necessary training load cannot always be achieved due to difficulties of coordinative nature. Thus, special-preparatory strength exercises are widely used. Fingerboard hanging can enhance maximal strength and intramuscular coordination. Campus board training is a proven in the practice extraordinary tool for developing explosive strength, improving rate of force development, as well as intramuscular and intermuscular coordination. System training is a special form of strength training used mainly to improve intermuscular coordination. For endurance training mostly interval methods for developing aerobic and anaerobic capabilities are used in the form of long bouldering or traversing, top rope and lead climbing.

As rock climbing has a variable character and many climbing conditions are possible (i.e. route length and inclination, holds' sizes, shapes and situation) it is difficult to standardize training and testing, to evaluate the performance limiting factors and to uncover workload control indicators. Nevertheless, the profound knowledge on different aspects of rock climbing is a precondition for enhancing performance through designing effective training methods which should highly reflect specificity to climbing.

Key words: *sport climbing, physiological responses to climbing, anthropometric characteristics of climbers, motor abilities in climbing*

Introduction

Rock climbing may be described as a "natural" physical activity, inherent in man as walking, running, or swimming. As modern lifestyle requires much less physical activity than it was necessary several decades ago, many people prefer rock climbing to meet the necessity of workload as an encoded factor for maintaining health status. However, rock climbing outdoors or at indoor artificial structures is practiced not only as a recreational but also as a competitive sport, as well as for non-competitive high performance climbing achievements, which is not typical for other sports.

The theory and methodology of sports training is an important issue for elite climbers, competitors and their trainers. A common feature of sport climbing is to climb at the limits of one's own capabilities. This is valid also for recreational climbers. Besides it is in the human nature to seek improvement. Therefore, the interest how to build the training process and which methods to use is great even among less skilled climbers. Considering the fact that popularity of climbing vastly increased, the necessity of providing knowledge related with the sport-specific training is apparent.

Rock climbing is an aggregate term for several sport disciplines in climbing. The popular meaning refers to climbing rock faces and getting on top of rock formations or reaching only the highest points of the routes. Schoeffl et al. [1] listed the following sub disciplines: sport climbing, bouldering, traditional climbing, alpine climbing, indoor- and even ice climbing. These types of climbing may be practiced in different styles i.e. on-sight (first try with no prior knowledge of the route), red-point (climbing a route after it has been previously attempted) or top rope (the climber could not fall because the rope runs from an anchor situated at the top). Different types and styles of climbing differ in intensity, duration, methods used for protection and terrain. This may set different physical and technical demands and may induce different physiological and psychological responses [2]. However, the performance limiting fac-

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tors and training methods may be considered identical. Only the levels and proportions of development of the decisive abilities would be different.

The historic development of all sports is following one pattern. At the first stage the sport achievements are increasing fast or exponentially. The second stage is linear and the third stage is asymptotic [3]. For example sport climbing has passed the inflexion point of the curve and has reached the saturation level (Fig. 1). Climbing records now will appear more rarely and the increases will be smaller. Thus, a scientifically backed training process is needed.

In order to conduct an effective training process it should be in conformity with rock climbing specificity. Thus, the scientifically backed training demands

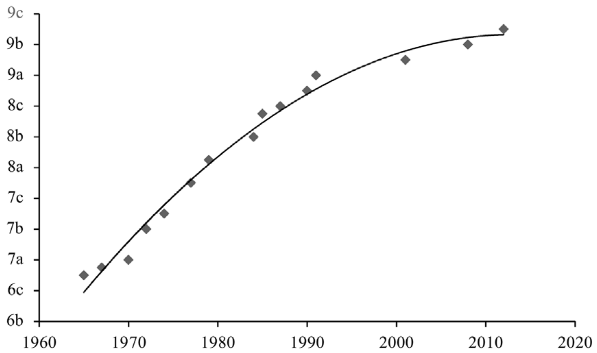

Fig. 1. *Trend of the sport achievements development in sport climbing. The regression model is estimated based on the climbing records*

comprehensive activity analysis [4]. The characteristic of rock climbing in this article will include workload parameters and physiological aspects. The athletic profile of elite climbers and the decisive performance factors will be also outlined. On this basis suitable exercises and methods of strength and endurance training for climbing will be proposed.

Characteristic of the workload in rock climbing

Physiological responses and long term adaptation depend on the combinations of workloads' intensity and volume, as well as on kinematical and dynamical parameters of the exercise. In order to maximize the training effect and to develop suitable methods for training, testing and monitoring in climbing, workload indicators must be first identified, quantified and applied in an optimal proportion in accordance to the training goal.

Volume indicators

Volume is the total amount of physical work. For volume indicators in climbing can be used: duration of the ascent, route length and number of hand moves. After observation of an indoor climbing competition mean duration of 4.5 min was estimated for the climbs [5]. However, the time for completing a sport climbing route may vary in a wide range depending on the route properties (Table 1). Multy-pitch routes or big walls require hours or days. In addition different types

Table 1. *Workload parameters describing the sport climbing sub discipline*

Workload parameters			Workload magnitude	Study
Volume	Route length		10–30 m up to 100+ m	Schoeffl et al 2010[1]
	Duration		1–10 min up to 20 min	Billat et al. 1995[6]; Watts et al. 1996[7]
	Duration depending on the cimbing style/type	ed-point	50 sec – 4 min	Koestermeyer 2001[8]
		and on-sight	3-10 min	
		Bouldering	29-50 sec	
	13-17 m 7c routes	# hand moves	23-26	de Geus et al. 2006[9]
		Duration	202 sec	
Intensity	Velocity		4.4 m/min	
	Forces applied on handholds during static positions		187 N, 307 N	Quaine, Martin 1999[10]
	Mean forces during competition (ladies world cup quarterfinals)		100 ± 30 N	Fuss, Niegl 2008[11]
Work-relief parameters	Contact time during sport climbing		mean 8.2 sec (range 2.7–22.5 sec)	
	Overall contact time-relaxation time ratios	Sport climbing	4:1	Schadle-Schardt 1998[5]
		Bouldering	13:1	White, Olsen 2010[12]
	Work-relief ratios and imbalances of load application	Right hand ambitious climbers	5:1	Donath et al. 2013[13]
		Left hand ambitious climbers	4:1	
		Right hand recreational climbers	7:1	
		Left hand recreational climbers	3:1	
	Immobilized body positions		36% of the total ascent	Billat et al. 1995[6]

and styles of rock climbing require different times. Nevertheless, volume can be easily prescribed during training. With respect to intensity this is not the case.

Intensity indicators

Intensity is the physical work completed per unit time and normally velocity and resistance are its indicators. Climbing is different from running or weightlifting. It is not possible to set training intensity through meters per second or kilograms. It is logical that performance is not related linearly with the speed of climbing (this affects to the least extend the "speed" competitive discipline). An optimal climbing speed should be achieved during an ascent in order to limit the effort's time and fatigue, respectively. The better the climber, the smaller are the contact times at the handholds [11]. Nevertheless, a very high velocity would cause disturbance in coordination, would lead to wrong tactical decisions and will result in a fall. Climbing specific velocity was registered to be 4.4 m/min [9] (Table 1). During climbing considerable resistance should be overcome (the one's own body mass). Therefore, resistance should be the more proper intensity indicator. Mean forces of 100 ± 30.1 N applied to handholds were measured during a Sport Climbing World Cup (ladies' quarterfinals) [11]. This result has an important descriptive value and such real time feedback information during training is applicable for sport technique and adequacy of force generation improvement. Unfortunately, force measurements cannot be applied for intensity guidance during climbing-specific conditioning. It is difficult to calculate the applied forces which will be different for each limb and will change depending on the rock relief, body postures and great variety of combinations and distances between handholds and footholds. When the inclination of the wall was changed with 10 degrees from vertical to overhanging direction the reliance on the upper limb support was vastly increased. In the vertical position grater vertical forces were applied to the footholds (57%) while in the overhanging position greater forces were applied to the handholds (62%) [14]. In another study it appeared that smaller holds induced variation only of the stabilizing horizontal forces during the anticipatory phase of postural adjustments [15]. It could be suggested that in cases where similar mechanical forces are measured the muscle exertion may be different due to different supporting surfaces. Thus, even if climbing holds are instrumented with force sensors, intensity in climbing cannot be prescribed by variables of the mechanical work.

One may assume that climbing grades of difficulty can serve as an intensity indicator but climbing difficulty depends on both: efforts magnitude of the single moves and duration of the climb. Shorter routes demanding greater percentage of the maximal voluntary contraction (MVC) can have the same difficulty as longer routes requiring easier single moves. Thus, climbing difficulty may be reckoned inappropriate for intensity prescription and subjective exertion scales, as proposed by Koestermeyer [8], are most applicable for now. Nevertheless, intensity can be prescribed as a percentage of the generated maximal force during special preparatory strength exercises on a fingerboard because for each hold or lath the maximal force can be calculated (i.e. in kilograms) and hangs with weights at a given percentage of the maximal force can be conducted (fig. 5).

Rock climbing is an activity which includes many sub-disciplines and styles. Each climbing route is different from the other. Moreover, routes' profile, holds' shapes, sizes and situation may vastly change along the ascent. Based on the above pointed characteristics, it appears that *rock climbing is neither only a strength nor an endurance sport but a physical activity with a variable character of the workload, demanding a complex development of the motor abilities, various and at the same time stable skills and highly mobile metabolic processes*. A very important characteristic of the workload in rock climbing is that more than one third of the time is spent in immobilized positions [6] and climbing involves sustained intermittent isometric contractions [16] with a restricting ratio of contraction and relaxation phases of the forearm muscles (Table 1). This should be the explanation of the nonstandard physiological responses to climbing. Therefore those who would suggest to control the training load through physiological instead of mechanical indicators may be also disappointed.

Physiological aspects

Physiological responses and bioenergetics are very complex and nonstandard in rock climbing. Thus, this article will cover only the main physiological aspects which are significant for the training practice. Rock climbing was qualified as a "very heavy work challenge" (8.4 – 9 metabolic equivalent) [17]. The Energy expenditure (12.6 kcal/min) was compared to running with a velocity of 12 km/h [18]. Having on mind the sustained intermittent isometric contractions in climbing, it may be assumed that the energy supply is a mixture of the three energetic systems and the dominating system should frequently change. The anaerobic systems should be involved due to the strenuous character of the sport and the aerobic system is activated due to the short relaxation phases. One study indicated that the main energy systems required are the aerobic and alactic systems [19]. These results should correspond predominantly to the whole body metabolism. What processes accrue locally at the most exerting and small in size muscle groups (the forearm muscles) still remains without an answer. It is plausible to assume that the anaerobic lactic system's contribution can be higher in some situations (20 sec – 2 min maximal efforts).

Climbers' maximal oxygen consumption ($\dot{V}O_2max$) from general running or cycling ergometry are relatively low (49 and 55 ml/min/kg) [6,9,17,20-22]. As some climbing routes may induce small oxygen consumption ($\dot{V}O_2$) during climbing (20.6 – 31.9 ml/min/kg) [6,18,20,23] it may be considered that the aerobic system plays a secondary role [6] in some climbing situations. Nevertheless some authors registered higher values during difficult climbing (up to 44.1 ml/min/kg) [9,19,24]. In addition running or cycling $\dot{V}O_2max$ is satisfying anyway and the upper-body $\dot{V}O_2peak$ values of climbers were higher than of a control group of non-climbers [25]. Therefore the importance of climbers' aerobic capacity should not be underestimated.

A unique response to climbing is the fact that the relationship between heart rate (HR) and $\dot{V}O_2$ does not correspond to the traditional one. HR disproportionally rises in comparison to $\dot{V}O_2$ [17,18,20]. Possible explanations are: 1) the repetitive isometric contractions which hinder the local blood flow; 2) the muscle metaboreflex (consisting of increased HR, cardiac output, central blood volume, systemic arterial blood pressure and vasoconstriction of renal and inactive muscles); 3) the fact that the arms are often above the level of the heart during climbing which causes a greater increase in HR than exercise with arms at waist level and 4) the reliance on both aerobic and anaerobic type of energy supply [16,18]. Another explanation for the existing $\dot{V}O_2$ – HR dissociation may be the smaller size of the most exerting upper-body muscles. Phillips et al. suggested that cardiac output is not likely a limiting factor in climbing but rather the upper extremity muscles' capabilities for oxygen uptake [26]. With respect to La, a similar phenomenon was observed. Giving the high corresponding HR values the post climbing lactate concentrations (La) were relatively small (up to 6.8 mmol/l) [4,18].

Nevertheless, La, $\dot{V}O_2$, as well as HR values from climbing are well below the same values from standardly used maximal incremental tests (i.e. cycling or treadmill ergometer tests) . These interesting results point out that the traditional way of using physiological parameters for training guidance is not applicable in sport climbing. In addition, physiological variables may be different even when climbing equally graded routes (i.e. routes with different inclination) [9,21] Therefore, Borg's rating of perceived exertion [27] or similar subjective exertion scales are most likely the only possibility for intensity control in climbing at the moment.

Physical characteristics of elite rock climbers

Anthropometric profile

Anthropometric variables of climbers are ubiquitous in climbing scientific literature. Climbers are described as not being tall and having a low percentage of body fat (% BF). Mean height values in elite male and female climbers ranged between: 171 – 179 cm and 162 – 164 cm, respectively [20,28-31]. The height is not a limiting factor of performance as taller climbers may have an advantage when the distances between the handholds are big but may also have a disadvantage if the handholds and foot holds are situated too close. The height of world-class boulderers correlated with the ranking at a world cup ($r = 0.5$, $P < 0.05$) [29]. This showed that in general the smaller competitors performed slightly better than the taller competitors. This was probably due to the way the competition routes were settled. Although % BF varied considerably even in-between very skilled climbers [29] and did not correlated strongly with climbing achievements, the low % BF is a distinguishing feature of elite climbers. It is believed among climbing society that the arm span relative to height (ape index) is an important variable. Indeed, elite climbers usually possess an index higher than 1.00 but it was not proven that the ape index correlates with climbing performance [32].

Motor abilities

Rock climbing is a whole body activity. An electromyography suggested that major muscle groups of the upper extremity, trunk, and lower extremity actively contribute in order to progress on the route [26]. The rate of exertion of the different muscle groups however is different. During finger-tip hanging and pull-ups the electrical activity of the flexor digitorum superficialis was the highest which remained so in the pull-ups task where brachioradialis had a close exertion rate [33]. This shows that generally fatigue in rock climbing is considered not to be systemic but localized in the forearm muscles [34].

Based on a review on studies in the field Watts noted that the reported values from handgrip dynamometry of elite climbers are not particularly high in comparison to recreational and active non-climbers [4]. Nevertheless, elite climbers possess significantly higher strength relative to body mass and sport-specific strength of the forearm flexors. It appears that training and testing in climbing should reflect the workload characteristics of the activity in details, including the specific climbing grip positions (crimp, open, pinch, etc.). Nevertheless, it should be considered that climbing can positively influence both specific and general fitness and that general working capabilities should not be underestimated. Among climbers of considerably wide ability range (4–11 UIAA) handgrip dynamometry and bent-arm hang scores correlated strongly with redpoint performance [35]. In addition 10 year old children who practiced regularly sport climbing had higher upper-body strength measured via general tests and similar results from tests for other motor abilities compared to aged matched physically active controls [36].

Major factors of performance

As climbers overcome considerable resistance (their body weight), the type of endurance in climbing is the strength endurance which was proved to be a performance factor of highest importance. Measured through climbing time until exhaustion it correlated strongly with climbing performance [29,37]. A more inside review of this ability is important for the training methods' design. The strenuous intermittent isometric contractions and the unfavorably short relaxation periods induce arterial occlusion of the exerting muscles and limit cell oxygen and fuel regeneration. Investigations showed that climbers are adapted to oppose to these negative influences by enhanced forearm vasodilatory capacity and increased re-oxygenation abilities in relation to non-climbers [38,39]. Mechanical manifestations of these adaptations were also presented. At exertion rates of 100% and 40% MVC rock climbers failed to maintain sustained isometric contractions longer than sedentary subjects. Logically climbers managed to cope better in specific rhythmic contraction tasks in between this range of intensity demonstrating in some cases greater times to exhaustion and in other similar times but greater oscillated forces [38-41]. If the efforts were continued after the subjects could no longer maintain the assigned force, climbers not only kept generating higher forces but also experienced les decrease in intensity (% MVC) than non-climbers [40].

Besides strength endurance, there are other motor abilities which were proven to be major factors of performance in rock climbing (Fig. 2). These are: sport-specific maximal strength of the forearm muscles relative to body mass [4,42,43], force gradient (rate of force development) of the finger flexors [44], explosive strength of the arm flexors [30,45], shoulder girdle strength endurance [35,36,41,42], core maximal strength [46], flexibility (hip joints, hip abduction in particular) [42,43,48].

Some researchers experimented methods for developing the decisive abilities in climbing. Guido Koestermeyer focused on the local aerobic energy metabolism and implemented higher number of "long routes" at lactate steady state with short breaks in-between [49]. This method improved significantly the strength endurance which decreased afterwards when only "normal climbing" was practiced (small number of difficult routes with full recovery rest intervals). Michailov developed an interval method, borrowed from the fartlek and represented by alternating repetitions of easy and "difficult" rotes with short rest intervals (Fig. 3) [21]. This method also significantly increased strength endurance and is expected to equally improve the mixed and the anaerobic energy supply. Schweizer's results supported the theory of the quadriga effect [50]. The author found that isolated action of a finger may vastly increase the generated force (up to 48%) compared with the force which a finger can reach by the participation of four fingers. The practical application of this finding may be: one finger strength training in elite climbers when the strength development has reached a saturation level. Furthermore López-Rivera & González-Badillo ascertained the more effective sequence of applying two training methods which was: dead hanging during the first four weeks of training using a bigger edge with added weight and dead hanging using minimum edge depth during the next four weeks [51].

Scientific literature unfortunately does not abound with papers on effects of training methods in climbing.

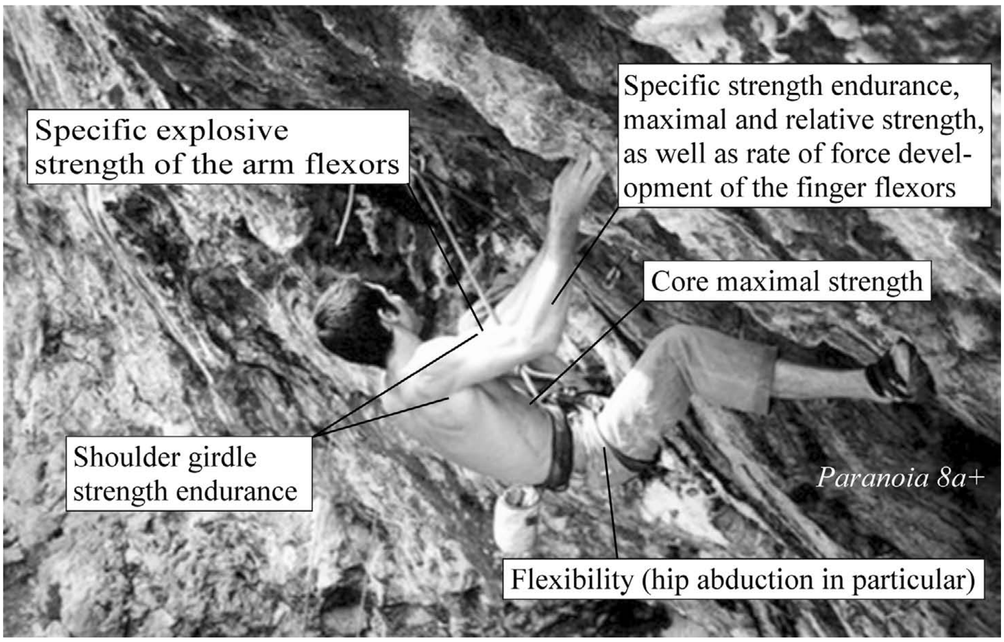

Fig. 2. *Motor abilities of major importance in rock climbing*

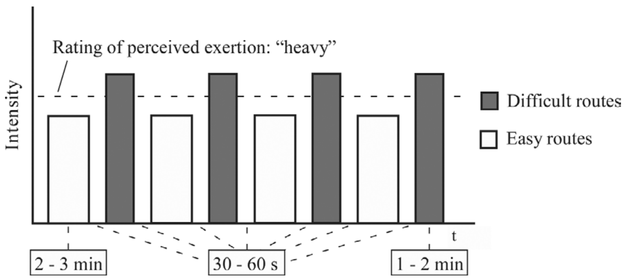

Fig. 3. *An interval method resembling the workload during performing the fartlek method. This interval method improves the compensatory mechanism of the organism and is suitable for sports with strenuous character, where the training load is difficult or not possible to be uninterrupted (Michailov 2006)*

Thus, the majority of the following means, methods and forms of sport-specific strength and endurance training are proposed based on the characteristic of climbing as a physical activity, following the principles of training science and due to the fact that they have been imposed as successful in the sport practice.

Methods of strength training

Sport-specific strength exercises

Sport-specific strength exercises are highly effective and develop strength in unity with sports technique [3]. Strength exercises of general coordination have their implication in curtain stages of the training macrocycle but they will not lead directly to improvement of sport-specific work capacity. This is true particularly in climbing. A sport-specific strength exercise for climbers is bouldering (Fig. 4). Table 2 and 3 contain workload parameters of two methods for sport-specific strength development.

Special-preparatory strength exercises

The necessary workload not always can be achieved through specific strength exercises due to coordination difficulty in some boulder problems [3]. Thus special-preparatory strength exercises are widely used.

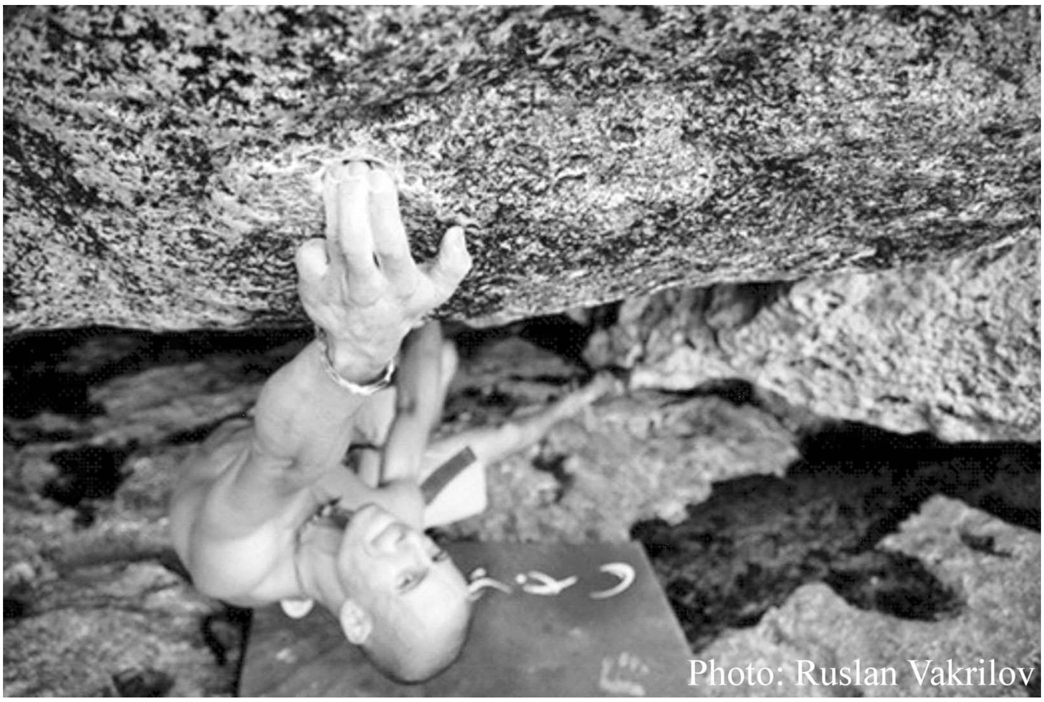

Fig. 4. *Bouldering is a highly effective sport-specific strength exercise*

Table 2. *Method 1, exercise: bouldering for maximal strength development*

Volume		Intensity	Rest intervals	Effect
Number of hand moves	Boulder problems	Maximal or near maximal difficulty of the boulder problems	3-5 min	Maximal strength, intramuscular and intermuscular coordination
From 1-2 up to 6-8	8-10			

Table 3. *Method 2, exercise: bouldering for achieving muscle hypertrophy*

Volume		Intensity	Rest intervals	Effect
Duration	Repetitions	To be adjusted in a way that will lead to maximal workload	> 60-90 sec	Hypertrophy, strength endurance
40-60 sec	3-5			

Fig. 5. *Dead hanging on a fingerboard variant 1: with additional weight*

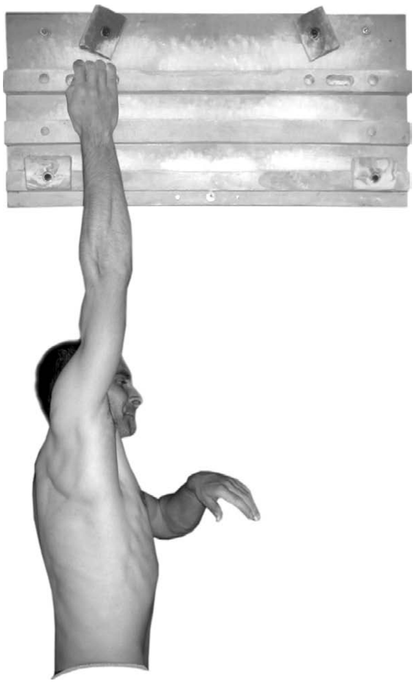

Fig. 6. *Dead hanging on a fingerboard variant 2: one hand hanging*

Fig. 7. *Dead hanging on a fingerboard variant 3: one hand hanging with aid of a finger of the other hand (only as much aid as needed in order to be able to bear the prescribed time)*

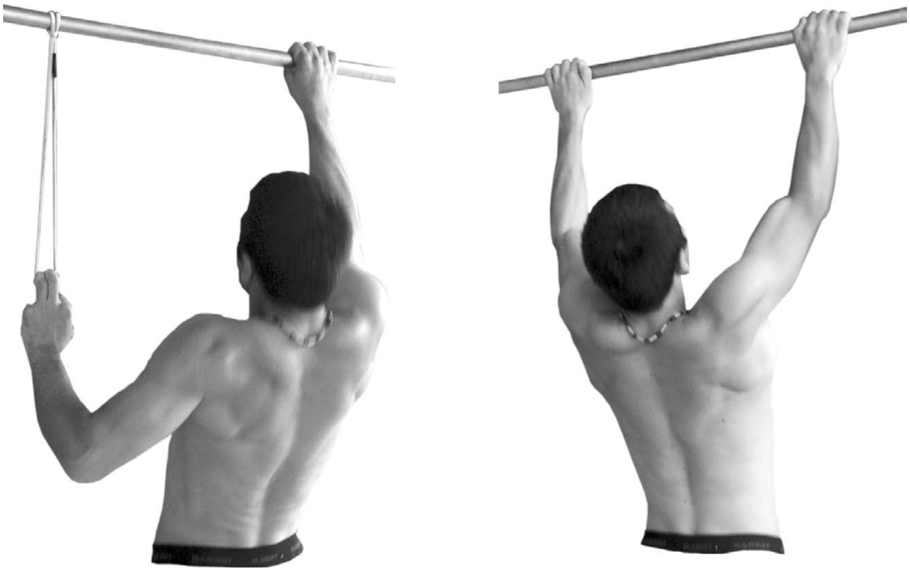

Fig. 8. *Different variants of pull-ups*

Fig. 9. *Attempting the "1, 4, 7" exercise on a campus board for developing upper-body explosive strength and forearm rate of force development*

They are similar in effort to bouldering but with differences in technique. The common ways to perform these exercises are using the following forms: finger board, campus board and system training. Examples of exercises and methods are given in (Fig. 5, 6, 7, 8, 9 and table 4, 5, 6, 7).

Campus board training (Fig. 9) is a proven in the practice extraordinary tool for developing explosive strength, improving force gradient, intramuscular and intermuscular coordination. Intensity should be near maximum. This should be achieved through the greatest velocity possible for the chosen laths' sizes. The repetitions number should be 4-6 and the rest intervals between them 2-3 minutes, respectively. These exercises should be done until failure (until phosphocreatine depletion). Many exercises can be performed on a campus board: making movements alternating hands, simultaneously moving both hands, only one hand moves and many variants of these basic exercises. Some of the most popular variants are: making moves by alternating hands and skipping laths (e.g. using laths' number: 1, 3, 5, 7; 1, 3, 6; 1, 4, 6/7; 1, 5, 7/8; etc.).

Table 4. *Method 3, exercise: dead hanging on a fingerboard with weights or without weights*

Volume		Intensity	Rest intervals	Effect
Duration	Repetitions	Maximal – near maximal	2-3 min	Maximal strength, intramuscular coordination
From 2-4 up to 6-8 sec	6-8			

Table 5. *Method 4: pyramidal rise and decrease of intensity and decrease and rise in duration, respectively; exercise: dead hanging on a fingerboard with weights or without weights*

Volume		Intensity	Rest intervals	Effect
Duration	Repetition number		2-5 min	Maximal strength, intramuscular coordination
6-8 sec	1	Moderately high (i.e. 85%)		
4-6 sec	2	High (i.e. 90%)		
3-4 sec	3	Near maximal (i.e. 95%)		
2-3 sec	4	Maximal (i.e. 100%)		
2-3 sec	5	Maximal (i.e. 100%)		
3-4 sec	6	Near maximal (i.e. 95%)		
4-6 sec	7	High (i.e. 90%)		
6-8 sec	8	Moderately high (i.e. 85%)		

Table 6. *Method 5, exercise: pull-ups*

Volume		Intensity	Rest between sets	Effect
Repetitions	Sets	40-70%	1-3 min	Hypertrophy, strength endurance
10-15	3-5			

Table 7. *Method 6, exercise: one arm pull-ups (in case the climber is not capable to perform one arm pull-up additional help by the other arm is applied)*

Volume		Intensity	Rests between repetitions	Rest between sets	Effect
Repetitions	Sets	Maximal – near maximal	20-30 sec	2-3 min	Maximal strength
4 (2 for each arm)	4-6				

System training is a special form of strength training used mainly to improve intermuscular coordination. The aim is to find the most economical positions and to perform the movements accurate (the center of gravity should be as close to the wall as possible, the legs should push as much as possible, etc.) [8]. This training can be orientated to improve the weak points of the climber. These may be problematic movements, holds, finger grip positions and body positions. Identical handholds are systematically arranged. They can be complex blocks with a combination of horizontal, vertical and diagonal holds, as well as “uppercuts”, holes, pinches and “slopers”. The identical moves and contractions lead to an one-sided and deeper specific effect.

Methods of endurance training

The strength endurance of the upper body musculature and the forearm muscles in particular is the major factor limiting climbing performance. Climbing involves display of strength endurance in combination with performing movements of complex coordination. Both bioenergetic factors and climbing skills highly determine the ability to sustain longer on a climbing route. Considering the specific character of the workload (i.e. the sustained intermittent static efforts) and aiming to build simultaneously an efficient technique and endurance, training for climbing should be conducted mainly through climbing exercise, not through exercises of general coordination. As climbing routes may vary in length and may demand different types of energy supply, both aerobic and anaerobic capabilities should be developed. The strenuous character of the activity necessitates mostly interval methods to be used (Table 8). They can be performed in the forms of: ropeless long bouldering or traversing, top rope and lead climbing.

Table 8. *Methods of endurance training*

	Method	Volume			Intensity	
		Duration	# hand moves	# repetitions	Borg's category ratio scale (CR-10)Borg	Rest intervals
Methods for developing aerobic capabilities	Continuous climbing	20-30 min			1-2	
	Climbing easy routes[8]	5-10 min	~ 30-40	5-6	2-3	1-2 min
	Climbing difficult routes[8]	3-4 min	~ 20-30	9	3-5	3 min
	Short intervals (classical interval method)	1-2 min	~ 15-20	5-6	4-6	1-2 min
	Intermittent climbing or hanging (enhancing myoglobin oxygen stores' functions)[3, 52]	10-15 sec		6-8	6-7	10-30 sec
	Repetitive method (maximal workload, full recovery)	3-8 min	~ 40-60	5-6	3-6	> 5 min
Methods for developing anaerobic capabilities	Climbing up to 1 min (enhancing glycolytic power)	20-60 sec	~ 6-15	3-5	7-8	3-5 min
	Climbing up to 2 min (enhancing buffer capacity)	1-2 min	~ 15-20	3-5	5-7	> 5 min
	Repetitive method (maximal workload, full recovery)	1-3	~ 15-25	3-5	8-9	> 20 min

Conclusion

A complete sport-specific training methodology in climbing is beyond the scope of this article. Many other methods and exercises could be also very useful. Moreover, a suitable periodization of training for climbing is an very important part of perfecting motor abilities and skills.

Climbing presents a challenge for investigators and trainers. Based on the fact that climbing is a polystructural sport with a variable character, it is difficult to standardize testing and training, to evaluate the performance limiting factors, to uncover workload control indicators and to completely explain the nonstandard physiological responses. Nevertheless, the profound knowledge on different aspects of rock climbing is a precondition for enhancing performance through designing effective training methods which should highly reflect specificity to climbing.

Declaration of interest

The author reports no conflict of interests.

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