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Title

Active recovery of the finger flexors enhances intermittent handgrip performance in rock climbers

Running head

Recovery of finger flexors in rock climbers

Authors

Jiří Baláš[1], Michail Michailov[2], David Giles[3], Jan Kodejška[1], Michaela Panáčková[1], Simon Fryer [4]

[1] *Faculty of Physical Education and Sport, Charles University in Prague, Czech Republic*

[2] *Department Theory of Sports Training, National Sports Academy, Sofia, Bulgaria*

[3] *Department of Life Sciences, College of Life and Natural Sciences, University of Derby, UK*

[4] *School of Sport and Exercise, University of Gloucestershire, Gloucester, UK*

Corresponding Author

Jiří Baláš

Sport Research Centre and Department of Outdoor Sports,

Faculty of Physical Education and Sport,

Charles University,

José Martího 31, 16252

Prague, Czech Republic.

Telephone: +420 220172017

E-mail: balas@ftvs.cuni.cz

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Abstract

This study aimed to 1) evaluate the effect of hand shaking during recovery phases of intermittent testing on time–force characteristics of performance and muscle oxygenation, and 2) assess inter-individual variability in the time to achieve the target force during intermittent testing in rock climbers. Twenty-two participants undertook three finger flexor endurance tests at 60% of their maximal voluntary contraction until exhaustion. Performances of a sustained contraction and two intermittent contractions, each with different recovery strategies, were analysed by time-force parameters and near infrared spectroscopy. The recovery with shaking of the forearm beside the body, led to a significantly greater intermittent test time ($\uparrow$ 22%, $P <$ 0.001), force-time integral ($\uparrow$ 28%, P = 0.001) and faster muscle re-oxygenation ($\uparrow$ 32%, P = 0.005), when compared to the hand over hold condition. Further, the ratio of intermittent to continuous test time distinguished specific aerobic muscular adaptations among sport climbers (2.02), boulderers (1.74) and lower grade climbers (1.25). Lower grade climbers and boulderers produced shorter duration contractions due to the slower development of target force during the intermittent test, indicating worse kinaesthetic differentiation. Both the type of recovery and climbing discipline determined muscle re-oxygenation and intermittent performance in rock climbers.

Keywords

Introduction

Sport climbing intermittent isometric contractions of the forearms, which are separated by dynamic whole body movements. As such, intermittent finger flexor endurance is considered a determining factor of success in sport climbing performance (Fryer, Stoner, Lucero, et al., 2015; Michailov, 2014). In order to assess finger flexor endurance previous research has used both continuous and intermittent testing protocols.

During a continuous sustained contraction to failure, when using body mass as a load (single or double hangs on a rung), finger flexor endurance increased with rock climbing ability (Baláš, Pecha, Martin, & Cochrane, 2012; Nachbauer, Fetz, & Burtscher, 1987). However, continuous tests at 40% of maximal voluntary contraction (MVC), which isolate the finger flexors, provide contradictory results (Fryer, Stoner, Scarrott, et al., 2015).

In order to better simulate patterns of finger flexor loads seen during rock climbing, intermittent tests were proposed with times of contraction from 5-18 sec, and with 2-12 sec passive rest (Ferguson & Brown, 1997; Grant et al., 2003; Philippe, Wegst, Muller, Raschner, & Burtscher, 2012; Quaine, Vigouroux, & Martin, 2003). However, total test time was not able to distinguish climbing ability groups, even on climbing specific testing devices (Fryer, Stoner, Dickson, et al., 2015; Macleod et al., 2007; Philippe et al., 2012). In order to provide a more ecologically valid measure, the force-time integral FTI was introduced. The FTI takes into account the higher maximal finger strength of advance and elite climbers (Macleod et al., 2007). The FTI represents the amount of muscular work, which includes both strength and endurance components, and was found to significantly increased with climbing ability (Fryer, Stoner, Dickson, et al., 2015; Philippe et al., 2012). Further, in support of these findings, analysis of muscle tissue oxygenation (tissue saturation index) showed that during the recovery periods between contractions, more advanced climbers had a greater amount of re-oxygenation than

lower grade climbers (Fryer, Stoner, Dickson, et al., 2015) and this re-oxygenation explained ~ 40% of variability in FTI (Macleod et al., 2007). Therefore, fast recovery between isometric contractions appears to represent a very important factor in sport-climbing performance. To our knowledge, no study has evaluated the effect of different recovery strategies, or previous training, on recovery speed in this unique group.

Intermittent tests and FTI characteristics clearly distinguish climbing ability groups and seem an important tool for the assessment of finger flexor endurance in rock climbers. However, several methodological concerns should be taken into consideration when using intermittent testing such as the optimal ratio between contraction and relaxation has not yet been determined; most previous research has used a ratio of 10 sec contraction and 3 sec recovery, which comes from the early evaluation of competition climbing (Schädle-Schardt, 1998). However, for the 2011 season onwards the IFSC (International Federation of Sport Climbing) imposed a maximal time to finish a competition route (6 minutes in qualification, 8 minutes in final), and altered the nature of routes to include more powerful moves. The contemporary competitive routes are, therefore, more demanding on strength components and may not allow for sufficient recovery previously seen on bigger holds. Consequently, future intermittent testing protocols should consider shorter contraction and recovery times which are at a higher percentage of MVC as these are likely to be more representative of the demands of competitive climbing.

No study that has used intermittent testing has indicated how the actual contraction and recovery times were calculated. These short times of recovery are very difficult to control and high inter-individual differences may exist in the time taken to achieve the desired target force even if controlled by acoustic or visual signals. A longer time to achieve the target force might slow deoxygenation in the early phase of contraction and consequently artificially increase participant time to exhaustion.

Whilst ascending a route, climbers naturally shake their hands close to the body to enhance recovery of the forearms. However, during all aforementioned intermittent tests, the hand and the arm were fixed in the same position. Placing a hand by the climber's side and shaking is likely to increase micro and macro vascular blood flow and consequently increase the delivery and perfusion of oxy-haemoglobin to the muscle tissue. Therefore, we hypothesized that shaking the hand during recovery periods will be associated with quicker re-oxygenation of the forearm muscles.

This study aimed to 1) evaluate the effect of hand shaking during recovery phases of intermittent testing on time–force characteristics of performance and muscle oxygenation, and 2) assess inter-individual variability in the time to achieve the target force during intermittent testing in rock climbers.

Methods

Study design. A one-factor experimental design with three levels (no recovery, with shaking, without shaking) was used to assess the effect of recovery on intermittent finger strength performance. The order of the recovery condition was randomly assigned. Climbers first completed a questionnaire, undertook anthropometric measurements and performed a warm-up. The warm-up consisted of five minutes stair walking, five minutes traversing on a climbing wall and five minutes individual one-arm intermittent hanging on a 30 and 23 mm wide rung using the open/slope grip position (Amca, Vigouroux, Aritan, & Berton, 2012). Following this, each participant performed 8 x five sec contractions at a force corresponding to 30% of body mass, with five sec recovery for the tested arm. After the warm-up, and ~ 10 minutes passive break, the maximal strength test was completed, followed by three endurance tests (continuous, and two intermittent tests) in a randomly assigned order with ~ 30 minutes active and passive recovery between the tests. Active recovery consisted of stair walking for ~ 10 minutes with a

heart rate of ~ 110-130 beats·min⁻¹. Low intensity exercise has been found to enhance recovery from climbing until exhaustion (Heyman, De Geus, Mertens, & Meeusen, 2009).

Participants. Twenty-two male sport climbers (mean age 28.3 yrs, $s = 6.5$; body mass 71.5 kg, $s = 8.3$; body height 178 cm, $s = 6$) volunteered to participate in the study. Red-point (RP) and on-sight (OS) grades for sport climbing and bouldering were determined using a validated self-report technique (Draper et al., 2011). To complete a sport route or boulder sequence by RP means to climb it without a fall after at least one previous attempt. The term OS is defined as a successful attempt without previous information or any attempts to ascend the route/sequence. Reported climbing abilities were transferred to the universal IRCRA (International Rock Climbing Research Association) scale, which is recommended for statistical analysis in all sport climbing and bouldering studies (Draper et al., 2015). Climbers reported their RP sport climbing ability to be between 5 and 10 UIAA (Union International des Associations d'Alpinisme), 4 to 8b Sport grade, 7 to 27 IRCRA scale. Furthermore, these climbers were post-hoc divided into three groups according to their climbing ability and the discipline they spent the most time conducting: lower grade climbers (N= 5), advanced and elite sport climbers (N= 11) and advanced and elite boulderers (N= 6) (Table 1). The study was approved by Ethical Committee of Charles University in Prague. All participants signed informed consent prior to any testing.

Finger strength measurement. To simulate climbing specific conditions a system for the assessment of climbers' finger strength and endurance (3D-SAC) was developed by the National Sports Academy, Sofia, Bulgaria (Fig. 1). 3D-SAC comprises of: 1) a 3D force sensor configuration with a place for mounting climbing holds (measuring range ± 2 kN, comprehensive accuracy 0.5%, accuracy of the analogue-to-digital converter 12 bit, sample rate 125 Hz); 2) a construction for adjusting the position of the climbing hold across the vertical axis; and; 3) a software package with the ability to store data in the memory of a computer. The system also enables the participants to control the intensity and duration of the efforts and the

rest intervals during each repetition, ensuring real time feedback information through visual and acoustic signals while performing the muscular endurance tests. This sport-specific dynamometer was calibrated for a wooden hold 23 mm deep, with a radius of 12 mm according to the theoretical model proposed by Amca et al. (2012) and later validated by Baláš et al. (2015). Consequently, these dimensions maximise potential finger flexor activation. The testing position saw the arm placed at 180° shoulder flexion and full elbow extension according recommendations made by Baláš et al. (2014). All measurements were undertaken in seated position with the shoulder of the tested arm placed vertically under the wooden hold (Fig. 1). If the climbers were able to hold themselves on one arm a vest of 10 kg was provided. Participants dried their hands using climbers chalk (magnesium carbonate) before testing. The wooden hold was regularly brushed to provide the same friction conditions for all participants.

Maximal strength testing (MVC) was completed twice separate by two minutes rest. On presentation of an acoustic signal, climbers were asked to progressively pull on the hold to load their maximal weight on to the tested arm for a period of five sec. Participants were verbally encouraged to achieve maximal effort. The highest value from the two trials was taken as their MVC for the following endurance tests. The next finger endurance test followed 10 minutes of recovery. The continuous strength test was undertaken in the same position at 60% of MVC. As before, the test started on an acoustic signal, the climbers had visual feedback to maintain the correct level of applied force. If the level of applied force dropped under 10% of target performance for more than one second, the test was automatically halted. The intermittent tests were performed at the same intensity (60% of MVC) with eight sec contraction and two sec recovery. The start and the end of the contraction periods were displayed on the device's monitor as well as being signalled acoustically. Climbers had to achieve the desired target force as quickly as possible. If the participant was not able to maintain the target force (-10%), the test was automatically stopped. The two intermittent tests were completed each with a different

recovery protocol: shaking the hand near the body with fingers directing down and non-shaking (keeping the hand relaxed over the testing hold).limited by the 2 sec rest interval between contractions. No specific rules were (Green & Stannard, 2010)

Fig. 1 near here

Muscle tissue oxygenation. The flexor digitorum profundus (FDP) was monitored for the level of muscle tissue oxygenation during the contraction and recovery periods. FDP is the dominant flexor muscle used during open grip positions (Schweizer & Hudek, 2011) and is easily palpable at one third of line between medial epicondyle and styloid process of ulna (Fryer, 2015). Near infrared spectroscopy (Moxy, USA) was used to assess the muscle tissue oxygenation. Moxy measures the ratio of the oxyhemoglobin concentration to the total hemoglobin concentration in the muscle in real time and reports it as a percentage, which is indicated as muscle oxygen saturation or muscle oxygenation (SmO_2). Data was stored and extracted from the internal memory of the device as a .csv file. An extraction program written in R used the data points to plot the time constant upon which the re-oxygenation time and point of maximal de-oxygenation were determined.

Statistical analysis.

From the device, *actual contraction time* and *total actual contraction time* were analysed. Actual contraction time represented the time of contraction in the limits 60% ± 10% MVC during one cycle of the intermittent test which supposed to last 8 sec. The target contraction time refers to the prescribed 8 sec contractions. Total actual contraction time was the time of the intermittent test spent in the limits 60% ± 10% MVC until exhaustion. Total target contraction time, hence, refers to the sum of 8 sec target contraction times until exhaustion. FTI

was calculated as average force applied on the hold in the target zone multiplied total actual contraction time.

Descriptive statistics (mean, *s*) were used to characterize the level of strength, endurance and muscle oxygenation for all participants and ability subgroups. As there were only a few participants in each of the subgroups, statistical comparison were reserved for only the whole group comparisons. To assess statistical differences between the shaking and non-shaking conditions, repeated measures ANOVA were calculated. Statistical significance was set to $P \leq 0.05$. Partial eta squared (η_p^2) was computed to estimate the coefficient of effect size. All calculations were completed in Microsoft Excel and IBM SPPS for Windows (Version, 22, Chicago, Il., USA).

Results

Anthropometric and climbing ability characteristics are provided in Table I. Sport climbing and bouldering specialists have similar RP and OS performance in sport climbing (< 1 degree differences on IRCRA scale), however, boulderers have higher bouldering RP performance (> 1 degree differences on IRCRA scale) than the sport climbers.

Table I near here

Differences between the two recovery strategies during intermittent tests are depicted in Table II. Recovery with shaking of the hand (fingers pointed down) near the body led to a significantly longer time of the test (↑ 22%), greater FTI (↑ 28%) and quicker muscle re-oxygenation (↑ 32%). Although no statistical analysis was calculated for the climbing ability subgroups, the largest differences between shaking and non-shaking were found in advanced and elite sport climbers. Contrary, no differences between shaking and non-shaking conditions were seen for the lower grade climbers. Sport climbers achieved the longest time and highest FTI in both

tests. Boulderers achieved similar times as the lower grade climbers; however, the FTI was substantially greater in boulderers.

The results of the maximal strength test are presented in Table I. The highest values of finger strength were found in the boulderers, lower ($\downarrow$ 13%) in sport climbers and substantially lower ($\downarrow$ 40%) in lower grade climbers. Boulderers were found to have shortest total time in a continuous test at 60% MVC in comparison to all subgroups and nearly as high FTI as sport climbers (Table II). Boulderers were also characterised by having the lowest level of forearm muscles' de-oxygenation, whereas the greatest de-oxygenation was reported for the advanced and elite sport climbers indicating highest oxygen desaturation in this group. Comparisons of force and time parameters between boulderers and sport climbers show that the FTI is influenced to a greater degree by the "force" component in boulderers and the "endurance" component in sport climbers.

Table II near here

The effect of recovery during intermittent protocol was assessed using the ratio of the total actual contraction time in the intermittent and continuous test. During the intermittent test with shaking, sport climbers, boulderers and lower grade climbers were able to contract for longer than in the continuous test by 102, 74 and 25% respectively (Table II). This time increase clearly distinguishes ability groups and climbing discipline preferences. Since it is related to aerobic capacity to restore energy during recovery, it will be named the "aerobic index". A significant relationship ($R^2 = 0.29$) was found between "aerobic index" and muscle re-oxygenation during intermittent testing.

The actual contraction time in one cycle of intermittent test in the target zone at 60% MVC ($\pm$ 10%) was 7.22 sec for shaking and 7.16 sec for no shaking, instead of the 8 sec prescribed. Moreover the actual time of contraction was significantly related to the total duration of

intermittent test for shaking recovery ($R^2 = 0.28$, $P = 0.01$) and no shaking recovery ($R^2 = 0.24$, $P = 0.02$) (Fig. 2), which is surprising as the longer total time in the test was associated with faster development of the target force. In other words, a higher degree of measurement error was associated with a shorter time of the intermittent test, which was found in lower grade climbers and boulderers (Table II). The lowest error was reported for advanced and elite sport climbers.

The mean force during intermittent tests was 56.6% ± 1.2% of MVC instead of prescribed 60% MVC, the differences were not related to the type of climbing or climbing ability.

Fig. 2 near here

Discussion

The main findings of the study were 1) recovery during intermittent testing significantly increased time to failure of the finger flexors, 2) type of recovery and preferred climbing discipline determines muscle re-oxygenation and performance in the test and 3) the ratio of time to failure for intermittent to sustained contractions termed the "aerobic index" is greater in sport climbers compared to boulderers and lower level climbers.

Shaking of the hand near the body (active recovery condition) was found to be a more effective recovery method than keeping the hand above the head. Its effectiveness may be connected with higher vasodilative responses and increased blood flow, as the forearm is placed under the level of the heart (Tschakovsky et al., 2004). Shaking of the hand near the body increased re-oxygenation by ~ 32%, in comparison to the non-shaking condition. Moreover, the amount of re-oxygenation was not related to climbing performance but rather to climbing disciplines. Despite this, advanced and elite sport climbers still achieved a greater level of re-oxygenation compared to lower level climber's, which is in agreement with current research (Fryer, Stoner,

Dickson, et al., 2015; Macleod et al., 2007; Philippe et al., 2012). In comparison, advanced and elite boulderers achieved very low levels of re-oxygenation. As such climbing ability on short bouldering routes may not be associated with the amount of re-oxygenation, but rather the type of climbing that the climbers predominantly took part in. It has been previously shown that in sport climbers, local vascular adaptations represent a higher reactive hyperaemic blood flow and capillary filtration capacity of forearm muscles (Thompson, Farrow, Hunt, Lewis, & Ferguson, 2014). These adaptations are due to the oxygen demands of the activity (sport climbing) generally lasting between two to seven minutes (Watts, 2004). However, little is known about the vascular adaptations within bouldering. It is possible that large changes in oxygenation would not be expected due to the much shorter duration of the climbs and the predominant energy system being anaerobic. A typical bouldering ascent lasts for ~ 30 sec, with sufficient time for recovery given between ascents (White & Olsen, 2010), the greatest demands are placed on neuromuscular adaptations and the anaerobic metabolism (Fanchini, Violette, Impellizzeri, & Maffiuletti, 2013; Michailov, 2014). Small local aerobic adaptation in boulderers may be supported by our findings, as boulderers achieved similar levels of re-oxygenation to that of the lower grade climbers.

Previous research has suggested that there are no differences between climbing ability groups in arterial blood flow during sustained contractions, however elite and advanced climbers are able to de-oxygenate both the flexor digitorum profundus and flexor carpi radialis to a greater extent than intermediate climbers and non-climbers (Fryer, Stoner, Scarrott, et al., 2015). Results from the current study are in agreement, advanced and elite sport climbers are able to de-oxygenate the flexor digitorum profundus to a higher extent than lower grade climbers. This suggests that in sport climbers the adaptations maybe associated with improved microvascular function rather than macro vascular adaptation. Moreover, boulderers achieved the lowest level of de-oxygenation indicating the lowest capacity for extracting O_2 from the perfused blood

during sustained contractions at 60% of MVC. When comparing average oxygenation between sustained and intermittent contractions, greater O_2 de-saturation (~ 10%) was demonstrated in the intermittent tests. It appears that intermittent contractions lead to higher O_2 depletion and are, therefore, more suitable to develop local muscular aerobic capacity.

In climbing the assessment of local aerobic capacity may be useful in order to monitor the effectiveness of training programmes. As the time to exhaustion and FTI involve both anaerobic and aerobic components, the "aerobic index", or the ratio of intermittent to continuous test time, is introduced as a means of assessing the forearm specific aerobic capacity in rock climbers. As the intermittent contraction times are longer than those seen during the sustained contractions (at the same 60% of MVC), the additional energy required must have been derived from the aerobic metabolism. In the current study the mean "aerobic index" in sport climbers was 2.02 (+ 102%, in comparison to the time of continuous test), which was substantially higher than both boulderers (1.74) and lower grade climbers (1.25). This suggests that sport climbers have a higher aerobic capacity in the forearm flexors, and this is likely a result of discipline specific training adaptations as it is greater than that seen in the boulderers. A further interesting finding was that the "aerobic index" was significantly related to the degree of re-oxygenation, confirming higher use of oxygen in advanced and elite sport climbers during recovery periods between intermittent contractions. Philippe et al. (2012) found 3.4 fold and 3.2 fold higher time of intermittent to sustained contraction at 40% MVC in female and male elite climbers, respectively and only 1.7 fold and 1.9 fold higher in female male non-climbers, respectively. A higher "aerobic index" in climbers and non-climbers in Philippe et al. study (2012), in comparison to our results might be explained by lower intensity of exercise and longer recovery between intermittent contractions.

A novel finding of the current study was how the actual contraction time may be affected by inter-individual variation in the time to achieve the target force. The fastest time to achieve 60%

MVC was found for sport climbers. It appears that climbing a sport route is associated with better and more precise kinaesthetic differentiation to apply force on holds, which is in agreement with the findings of Fuss and Niegl (2008) and Baláš et al. (2014), who found lower hold loading in female sport climbers with increasing climbing ability. A longer time to achieve target force in boulderers and lower level climbers (~ 1 sec) (Fig. 2) might have increased the level of re-oxygenation and, prolonged their performance in the intermittent tests. Moreover, if the FTI were to be calculated as 0.6 (% MVC) multiplied the total target contraction time, the FTI will be substantially overestimated. In the current study, the mean actual contraction time was ~0.8 sec lower than the target time of eight sec, and the mean force was only 56.6% and not 60%, as prescribed. As such, the mean FTI would be by 22% lower. Therefore, the time of contraction and the applied force represent a notable source of error if they are not calculated from the actual contraction time and from "real" applied force.

Several limitations should be acknowledged. The authors are aware that the small sample size in the climbing abilities subgroups limits the possibilities to perform thorough statistical analyses. Further studies with large sample sizes of sport climbers and boulderers of similar abilities should be conducted to confirm the proposed suggestion on discipline groups' differences. Fatigue may have influenced the endurance tests despite the active recovery used; especially in lower grade climbers, who are not used to repeated intermittent contractions until exhaustion. However, the randomly assigned order of endurance test should have reduced the effect of fatigue. The spectroscopy during tests till exhaustion might be affected by body fat or lactic acid production which influences the oxy-haemoglobin spectra reflection. As body fat in forearms is generally low, we have not assumed changes in oxygenation due to fat distribution. However, lactic acid might have influenced oxy-haemoglobin analysis during the last part of endurance tests. Consequently, the average oxygenation might be partially biased.

Conclusions

A new diagnostic parameter "aerobic index" based on the effect of recovery was introduced. The index provides a simple way to assess local aerobic capacity of the forearms which is suitable for evaluating the effectiveness of local endurance training programmes as well as distinguishing ability group differences. An important and novel finding was that shaking the hand near the body during intermittent contractions is a more effective method of recovery compared to maintaining the recovering hand over the hold. This is because the action induces higher muscle re-oxygenation and increases the overall time of the test in rock climbers. The amount of muscle re-oxygenation is related more to climbing disciplines rather than climbing ability. The use of intermittent tests requires devices that are able to record applied force and time in the target limits, as high inter-individual variation in contraction speed may increase measurement error, particularly if the force time integral is calculated.

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Table I. Mean ± *s* anthropometric, climbing ability, and strength characteristics of participants. Climbing ability is indicated according the International Rock Climbing Research Association (IRCRA) scale.

	Age (yrs)	Body mass (kg)	Height (cm)	Sport RP (IRCRA)	Boulder RP (IRCRA)	Finger strength (N)	Finger strength (kg) related to body mass (kg)
LG (N = 5)	25.5 ± 4.1	76.5 ± 8.5	182 ± 8	9.8 ± 3.3	12.2 ± 1.1	410 ± 107	0.54 ± 0.12
SC (N = 11)	31.2 ± 6.1	68.7 ± 5.7	175 ± 5	19.9 ± 2.7	21.4 ± 3.5	539 ± 82	0.81 ± 0.14
BC (N = 6)	25.5 ± 7.3	72.6 ± 10.9	178 ± 6	19.0 ± 3.5	22.7 ± 3.5	659 ± 113	0.94 ± 0.19
Total (N = 22)	28.3 ± 6.5	71.5 ± 8.3	178 ± 6	17.4 ± 5.1	19.6 ± 5.1	542 ± 128	0.78 ± 0.20

LG = lower grade climbers, SC = sport climbers and BC = bouldering climbers

Table II. Mean $\pm$ *s* performance characteristics and muscle oxygenation in the continuous, shaking and non-shaking intermittent tests. *P* values and η_p^2 designate differences between intermittent tests only, values in italics indicate tests' results for climbing ability subgroups.

	Participants	Continuous	Shaking	Non-skaking	Differences shaking non-shaking	*P*	η_p^2
Total actual contraction time (s)	*LG (N = 5)*	*60.2 ± 23.0*	*75.4 ± 42.3*	*72.6 ± 33.8*	*2.8 ±14.2*		
	SC (N = 11)	*65.9 ± 9.9*	*133.2 ± 45.8*	*99.4 ± 30.9*	*33.8 ± 19.4*		
	BC (N = 6)	*48.1 ± 9.8*	*83.8 ± 32.1*	*67.3 ± 24.6*	*16.5 ± 23.3*		
	Total (N = 22)	59.8 ± 115.1	104.9 ± 48.5	86.2 ± 33.2	22.0 ± 22.7	**< 0.001**	**0.497**
Force-time integral (N.s.kg^{-1})	*LG*	*162 ± 23*	*193 ± 57*	*191 ± 27*	*2.4 ± 41.2*		
	SC	*285± 58*	*579 ± 257*	*425 ± 164*	*153.9 ± 106.7*		
	BC	*244 ± 67*	*418 ± 140*	*345 ± 159*	*72.8 ± 120.0*		
	Total	246 ± 73	447 ± 248	350 ± 167	97.4 ± 114.7	**0.001**	**0.43**
Average tissue oxygenation during whole test (% SMO$_2$)	*LG*	*35.4 ± 9.4*	*32.2 ± 13.9*	*27.0 ± 14.0*	*5.1 ± 16.2*		
	SC	*30.1 ± 8.2*	*19.7 ± 8.7*	*22.2 ± 11.0*	*-2.5 ± 9.5*		
	BC	*39.8 ± 8.0*	*23.7 ± 7.3*	*20.7 ± 6.4*	*3.0 ± 6.8*		
	Total	33.9 ± 9.1	23.6 ± 10.5	22.9 ± 10.5	0.7 ± 10.7	0.752	0.005
Tissue re-oxygenation during recovery (% SMO$_2$)	*LG*		*11.8 ± 4.3*	*9.2 ± 3.7*	*2.6 ± 3.8*		
	SC		*18.0 ± 5.5*	*12.7 ± 6.1*	*5.2 ± 5.4*		
	BC		*11.4 ± 5.5*	*9.9 ± 2.5*	*1.5 ± 6.3*		
	Total		14.8 ± 6.0	11.2 ± 5.0	3.6 ± 5.4	**0.005**	**0.322**

LG = lower grade climbers, SC = sport climbers and BC = bouldering climbers

Fig. 1. The device developed to measure finger specific strength. Body and finger position are shown for the maximal strength tests, continuous and two intermittent tests.

 Fig 2. Target and actual contraction time of 60% MVC during intermittent testing with two different recovery strategies. The line of target contraction time represent 8 sec of prescribed contraction.