Differences in forearm strength, endurance and hemodynamic kinetics between male boulderers and lead rock climbers

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Abstract

This study examined differences in the oxygenation kinetics and strength and endurance characteristics of boulderers' and lead sport climbers. Using near infrared spectroscopy 13-boulderers, 10-lead climbers and 10-controls completed assessments of oxidative capacity index and muscle oxygen consumption ($m\dot{V}O_2$) in the flexor digitorum profundus (FDP) and extensor digitorum communis (EDC). Additionally, forearm strength (maximal volitional contraction MVC), endurance (force time integral FTI at 40% MVC) and forearm volume (FAV and ΔFAV) was assessed. MVC was significantly greater in boulderers compared to lead climbers (mean difference= 9.6, 95% CI 5.2 – 14 kg). FDP and EDC oxidative capacity index were significantly greater (p= 0.041 and 0.013 respectively) in lead climbers and boulderers compared to controls (mean difference= -1.166, 95% CI (-3.264 – 0.931 s); mean difference= -1.120, 95% CI (-3.316 – 1.075 s) respectively) with no differences between climbing disciplines. Climbers had a significantly greater FTI compared to controls (mean difference = 2205, 95% CI= 1114 – 3296 and mean difference = 1716, 95% CI= 553 – 2880 respectively) but not between disciplines. There were no significant group differences in ΔFAV or $m\dot{V}O_2$. The greater MVC in boulderers may be due to neural adaptation and not hypertrophy. A greater oxidative capacity index in both climbing groups suggests that irrespective of climbing discipline, trainers, coaches and practitioners should consider forearm specific aerobic training to aid performance.

Key words: Oxidative capacity, microvascular adaptation, near infrared spectroscopy, blood flow, perfusion, sport climbing

Introduction

Lead climbing and bouldering both rely heavily on the performance of the forearms, but are potentially divergent with respect to the dominant metabolism. Although both disciplines have substantially grown over the past two decades, the majority of the literature has focused solely on lead climbing (Kodejska, Michailov, & Balas, 2015). The International Federation of Sport Climbing (IFSC) describes lead climbing as a competitor clipping into protection points as they climb. Progression along this line determines the competitors ranking. As such, lead climbers require notable forearm endurance, and with the exception of crux moves (the most difficult section on a route), is suggested to have a dominant reliance on the aerobic metabolism (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Fryer et al., 2012). Conversely, the IFSC describe bouldering as short climbs, these are attempted without ropes but with landing mats for protection and the number of boulders climbed determines the competitor ranking. Consequently, boulderers' have been observed to have a greater finger strength and rate of force development (Fanchini, Violette, Impellizzeri, & Maffiuletti, 2013), which likely requires a larger contribution from the anaerobic metabolism.

It is evident that forearm strength and endurance are of the upmost importance for rock climbing performance, and as such forearm oxygenation kinetics have become a focal point of research. However, there is a paucity of data on the oxygenation responses in the forearms of boulderers. Recently one previous study investigating lead climbers used the oxidative capacity index of the flexor digitorum profundus (FDP) to predict red-point performance (Fryer et al., 2016). Given that the oxidative capacity index reflects the delivery, perfusion, and consumption of oxygen within the muscle tissue; it is likely that the rate of muscle oxygen consumption ($m\dot{V}O_2$) may influence the oxidative capacity index i.e., increase time to half recovery of the tissue saturation index (TSI) however, this has not been investigated.

Given that both climbing disciplines rely heavily on forearm performance but differ in terms of route length, it is pertinent that research aiming to quantify the strength, endurance, and oxygenation response of both disciplines, as well as the mechanisms behind potential differences is investigated. Particularly as such knowledge could be used to improve precision in exercise prescription and identification of optimal training targets. Therefore, the aim of the current study was to determine forearm characteristics including: oxidative capacity index, $m\dot{V}O_2$, anthropometric and strength and endurance in lead climbers, boulderers, and controls. Specifically it was hypothesized that lead climbers would have a greater oxidative capacity index and $m\dot{V}O_2$ in comparison to boulderers. These findings will help to inform trainers, practitioners, and coaches.

Method

Participants

In accordance with classifications set by Draper et al. (2016) thirteen advanced male lead climbers and 10 advanced male boulderers volunteered to participate in the current study. All climbers were not cross discipline trained, as they only climbed in their respective discipline. Eleven male controls matched for age, height, mass and training but not climbing volunteered to take part in the current study. Anthropometric and demographic data for all participants is presented in Table 1. All participants were healthy, non-smoking and were not taking any vascular acting medications. Institutional ethics which met the standard of both the journal and the Declaration of Helsinki of the World Medical Association was granted prior to recruitment and testing.

Table 1. Demographic characteristics of control, lead climbing and bouldering groups.

Dependent variable	Control	lead climbing	Bouldering	One-way ANOVA	
	Mean ± SD	Mean ± SD	Mean ± SD	*p* value	% variance (η_p^2)
Age (yrs)	26.7 ± 4.2	26.1 ± 5.3	27.5 ± 5.7	0.804	1.4
Height (cm)	180.0 ± 5.0	177.6 ± 8.7	175.8 ± 8.7	0.318	7.7
Mass (kg)	74.9 ± 13.5	71.1 ± 8.2	72.7 ± 6.2	0.643	2.8
Body fat (%)	16.97 ± 8.39	14.9 ± 7.96	10.01 ± 3.89	0.067	16.0
Flexor skinfold (mm)	4.35 ± 1.63	4.0 ± 1.02	3.03 ± 0.60*	0.040	18.8
Extensor skinfold (mm)	4.59 ± 2.05	3.87 ± 0.85	3.03 ± 0.60	0.124	12.6
Resting FAV (ml)	968.7 ± 195.9	1026.3 ± 197.9	1115.9 ± 100.4	0.205	9.7
Climbing time (hrs·week)	N/A	9.5 ± 4.8	8.1 ± 4.9	0.510	2.1
Climbing experience (yrs)	N/A	7.8 ± 3.9	7.1 ± 4.3	0.716	0.6
Climbing ability	N/A	Advanced (Level 3)	Advanced (Level 3)	N/A	N/A

NB: FAV = forearm volume. SD = standard deviation. The % variance is the estimated variance explained by the mean effects within each group for the named variable.
* Significantly different (p<0.05) from the control group (p<0.05).
Climbing ability was determined based on the best 6-month red-point grade; all were converted to IRCRA grades and categorized according to Draper at al., (2016).

Procedures

All testing was conducted on a single visit to an environmentally controlled exercise physiology laboratory with the temperature being maintained at 21^{o}c. Participants were asked not to consume food for 4 hours prior to testing and to refrain from consuming caffeine or alcohol for a minimum of 12 hours prior. Upon arrival to the laboratory, each participant filled out forms for the determination of health history, informed consent, demographic data and, where relevant, a validated self-reported climbing ability (Draper et al., 2011). Following this, anthropometric data was collected, including resting forearm volume (FAV) [water displacement], forearm circumference, stature (Holtain, Ltd, Crymych, UK) and body composition. Body composition was assessed using the BodPod system (Cosmed, Rome, Italy) which utilizes air displacement plethysmography.

Participants were asked to lie in a supine position on a massage therapy bed for 20 min of quiet rest in a dimly lit room. Subsequently, near infrared spectroscopy (NIRS) was used to determine resting $m\dot{V}O_2$ and oxidative capacity index of the FDP and extensor digitorum communis (EDC) of the dominant forearm. The FDP has been assessed in previous lead climbing research as it has been reported to be the most important finger flexor for rock climbing performance (Philippe, Wegst, Müller, Raschner, & Burtscher, 2011). No known research has determined responses to the finger extensors. Due to the large forces placed on the finger flexors during climbing, the finger extensors would likely be activated to oppose the isometric contraction. As such the EDC was chosen due to its primary role in extending the four medial digits of the hand (Tortora & Derrickson, 2008). Following the haemodynamic assessments, participants were then asked to perform a self-selected warm-up followed by determination of finger flexor maximal volitional contraction (MVC - open crimp). Following light cycle ergometry to aid recovery (Heyman, de Geus, Mertens, & Meeusen, 2009), the force time integral (FTI) during an intermittent test for failure was determined using an open crimp at 40% MVC until volitional fatigue. In accordance with Philippe et al. (2011), MacLeod et al. (2007), and Fryer, Stoner, Lucero, et al. (2015), the intermittent test consisted of a contraction to rest ratio of 10:3s. Immediately after volitional fatigue the post forearm volume was taken to enable calculation of a delta score (ΔFAV). MVC/ΔFAV was calculated to help elucidate whether potential group differences were due to hypertrophy or neural adaptation.

Finger apparatus and exercise protocol

The fingerboard apparatus is the same board that was previously used by Fryer, Stoner, Lucero, et al. (2015) and based upon the work by MacLeod et al. (2007) and Philippe et al. (2011). The apparatus has a rock climbing specific handhold attached to a load-cell which once calibrated can determine a rock climbing specific measure of strength and endurance in the finger and wrist flexors. With a coefficient of variation of 0.5%, the between-day reliability of the device is considered excellent. For comparability to the majority of previously published research in the area, 40% MVC was chosen as a performance measure to determine the FTI [FTI = 0.4 x length of contraction (s) x force (N)]. To determine MVC three maximal trials were used and the highest was recorded.

Forearm volume and circumference

In line with Boland and Adams (1996), forearm volume was measured using a water displacement volumeter both pre and immediately post intermittent contraction test to volitional fatigue. Forearm volume represents the volume from the base of the carpus to the crease in the elbow joint; displaced water was weighed to determine volume. Forearm circumference was measured using an anthropometric tape measured at the widest point of the individuals forearm.

Near-infrared spectroscopy (NIRS)

Continuous-wave NIRS was used to measure forearm $m\dot{V}O_2$ and oxidative capacity index at the FDP and EDC. This technology relies upon the relative transparency of tissue to infrared light and the oxygen dependent absorption characteristics of haemoglobin (Hb) to determine oxy-haemoglobin (O_2Hb) and deoxyhaemoglobin (HHb), the sum of which is total haemoglobin (tHb). Application of the modified Beer-Lambert Law allows for relative concentration changes in chromophores to be determined (Delpy et al., 1988: Ferrari et al., 2002), whereas the use of spatially resolved spectroscopy (SRS) allows for the determination of a TSI (Patterson, Chance, & Wilson, 1989). It is important to note that NIRS cannot distinguish between myoglobin and Hb chromophores. For clarity the combination of Hb and myoglobin will be referred to as Hb in this paper.

The NIRS system used in the present study consisted of two independent Artinis Portalite optodes (Artinins Medical Systems BV, Zetten, The Netherlands) sampling at 25 Hz. The optodes comprise of three light-emitting diodes, positioned 30 mm, 35 mm, and 40 mm from a single receiver, which transmitted infared light at two wavelengths (760 nm and 850 nm). A differential path-length factor of 4.0 was used to correct for photon scattering within the tissue (Ferrari, Wei, Carraresi, De Blasi, & Zaccanti, 1992). The optodes were fixed to the skin close to the belly of the FDP and EDC with bi-adhesive tape and covered with an opaque cloth to prevent signal contamination by ambient light. Measures of skinfold thickness were taken from the sites beneath the positioned optodes and are reported in Table 1. The observed FDP and EDC skinfolds are notably less than the 6.4 mm which has previously been reported to affect NIRS signal quality (Van Beekvelt, Borghuis, Van Engelen, Wevers, & Colier, 2001). Accordingly, the effect of adipose tissue on NIRS signal was thought to be negligible.

Flexor and extensor locations

Both the FDP and EDC NIRS probes were paced in accordance with (Philippe et al., 2011). For the FDP, a line was drawn on the anterior side of the forearm from the medial epicondyle of the humerus to the base of the carpus (lunate) proximal to the ring finger. The optode was placed

33% distal to the epicondyle of the humerus. For the EDC a line was drawn from the medial epicondyle of the humerus to the ulnar styloid process. The optode was placed 33% distal to the epicondyle of the humerus. It is acknowledged that due to the complexity of the forearm muscular anatomy and the fact that ultrasound was not used to determine the FDP and EDC location, the NIRS optodes may, in part, overlay muscles adjacent to the target muscles.

Muscle oxygen consumption ($m\dot{V}O_2$)

Muscle oxygen consumption was derived from NIRS using the arterial occlusion method, by evaluating the rate of increase in HHb (De Blasi, Almenrader, Aurisicchio, & Ferrari, 1997). Briefly, a Hokanson rapid inflation cuff (Hokanson Inc, WA, USA) was fitted to the upper arm, proximal to the NIRS optodes. Following resting measures, the cuff was rapidly inflated to 220 mmHg and sustained for 20 s. Three consecutive arterial occlusions were conducted separated by a deflation period of 1 minute. Concentration changes of HHb were expressed in micromolars per second ($\mu mol \cdot s^{-1}$) and converted to millilitres O_2 per minute per 100 gram tissue ($mlO_2 \cdot min^{-1} \cdot 100g^{-1}$) using the following formula;

$$m\dot{V}O_2 = Abs(((\Delta HHb \times 60)/(10 \times 1.04)) \times 4) \times 22.4/1000 \text{ in } mlO_2 \cdot min^{-1} 100g^{-1}$$

where each Hb molecule blinds four O_2 molecules and it was assumed that the molar volume of gas is 22.4 L under standard temperature pressure dry (STPD) conditions (Van Beekvelt, Colier, Wevers, & Van Engelen, 2001). A value of 1.04 $kg \cdot L^{-1}$ was used for muscle density (Vierordt, 1906).

Oxidative capacity index

Oxidative capacity index was derived using NIRS by measuring the time to half recovery (s) of TSI following 5 min of arterial occlusion (Chance, Dait, Zhang, Hamaoka, & Hagerman, 1992). Expressed as a percentage, TSI is calculated as $(O_2Hb/(O_2Hb + HHb)) \times 100$ and reflects both the influx of oxygenated arterial blood and the continued consumption of O_2 during recovery from ischemia. Time to half recovery of TSI has previously been found to be a significant predictor of lead rock-climbing performance (Fryer et al., 2016). Following $m\dot{V}O_2$ determination, participants were asked to perform light (~10 % MVC) handgrip dynamometry (HGD) exercise to activate metabolism. Immediately following HGD, the rapid Hokanson cuff was inflated to 220 mmHg and sustained for 5 minutes. The cuff was then released and recovery values of TSI were recorded for 5 min. Time to half recovery of TSI was calculated from the point of maximum deoxygenation at the end of occlusion to highest re-oxygenation percentage achieved during hyperaemia. A reduction in time to half-recovery is concomitant with an increase in skeletal muscle oxidative capacity index (McCully et al., 1994).

Statistical analysis

All data is presented as mean ± standard deviation (SD). For meaningfulness, mean difference (MD) and 95 % confidence intervals (CI) are used. All variables were assessed and found to be normally distributed with equal variance. For each independent variable a one-way ANCOVA was performed with the covariates age and climbing experience (of which none were shown to be significant). If a significant ANOVA was found a series of post-hoc Bonferroni tests were used to determine where the group differences lay. All analysis was performed using Statistical Package for Social Sciences (SPSS, Version 22.0). For all statistical analysis the critical α-level was set at 0.05.

Results

Table 2. Performance and haemodynamic data for control, lead climbing and bouldering groups.

Dependent variable	Control	Lead climbing	Bouldering	One-way ANOVA	
	Mean ± SD	Mean ± SD	Mean ± SD	*p* value	% variance (η_p^2)
MVC (kg)	19.2 ± 2.5	29.4 ± 4.0*	36.9 ± 6.9*,**	<0.001	67.1
FTI (N)	26063 ± 8180	47696 ± 15131*	42899 ± 13626*	0.001	36.9
MVC (kg)/ BW (kg)	0.26 ± 0.05	0.39 ± 0.06*	0.50 ± 0.08*,**	<0.001	66.4
MVC (kg) /ΔFAV (ml)	0.20 ± 0.04	0.27 ± 0.05*	0.33 ± 0.05*,**	<0.001	51.6
Δ FAV (ml)	30 ± 29	49 ± 43	32 ± 46	0.451	5.0
Time to fatigue (s)	339 ± 105	426 ± 100*	287 ± 70**	0.005	29.1
Flexor time to half recovery (s)	8.96 ± 3.58	7.79 ± 1.46*	7.84 ± 1.82*	0.041	19.7
Extensor time to half recovery (s)	8.60 ± 3.20	6.32 ± 2.07*	5.54 ± 1.17*	0.013	25.2
Flexor $m\dot{V}O_2$ ($\mu L \cdot min^{-1}$)	0.07 ± 0.02	0.07 ± 0.01	0.08 ± 0.02	0.266	8.7
Extensor $m\dot{V}O_2$ ($\mu L \cdot min^{-1}$)	0.15 ± 0.23	0.08 ± 0.02	0.13 ± 0.07	0.425	5.7

Abbreviations: MVC, maximum voluntary contraction; FIT, force –time integral; BW, body weight; FAV, forearm volume; $m\dot{V}O_2$, muscle oxygen consumption; SD = standard deviation
NB: The % variance is the estimated variance explained by the mean effects within each group for the named variable.
* Significantly different from the control group (p<0.05).
** Significantly different from lead climbing (p<0.05).

Forearm strength and endurance characteristics

The MVC of climbers (lead climbers and boulderers) was significantly greater than controls (mean difference = 17.8, 95% CI [13.2 – 22.3 kg] and mean difference = 8.2, 95% CI [3.9 – 12.5

kg]), respectively; additionally boulders had a significantly greater MVC than lead climbers (mean difference = 9.6, 95% CI [5.2 – 14 kg]). Time to fatigue during the intermittent test to failure was significantly longer for lead climbers compared to boulderers (mean difference = 138, 95% CI [58 – 220 s]) and the control group (mean difference = 87, 95% CI [8 – 166 s]). The control group recorded a longer time to fatigue than the boulderers (mean difference = 52, 95% CI [33 – 136 s]). Both lead climbers and boulderers had a significantly greater FTI compared to controls (mean difference = 2205, 95% CI [1114 – 3296] and mean difference = 1716, 95% CI [553 – 2880], respectively) but the FTI could not significantly distinguish between climbing disciplines. To determine relative strength MVC was divided by body mass and this was found to be significantly greater in lead climbers and boulderers compared to controls (mean difference = 0.128, 95% CI [0.066 – 0.190 MVC/kg] and mean difference = 0.252, 95% CI [0.186 – 0.318 MVC/kg] respectively); and boulderers had a significantly greater MVC/kg than lead climbers (mean difference = 0.124, 95% CI [0.061 – 0.188 MVC/kg]). Similar significant differences were found for MVC/FAV with both lead climbers and boulderers having a greater MVC/FAV than the control group (mean difference = 0.073, 95% CI [0.030 – 0.177 MVC/mL] and mean difference = 0.130, 95% CI [0.083 – .176 MVC/mL] respectively); however, unlike MVC/BW, boulders were significantly greater than lead climbers (mean difference = 0.056, 95% CI [0.012 – 0.101 MVC/mL]).

Haemodynamic responses

The oxidative capacity index of the FDP was significantly greater (quicker time to half recovery) in both lead climbers and boulderers compared to the control group (mean difference = -1.166, 95% CI [-3.264 – 0.931 s] and mean difference = -1.120, 95% CI [-3.316 – 1.075 s] respectively). The same was found in the EDC with lead climbers and boulderers having a greater oxidative capacity index than controls (mean difference = -2.287, 95% CI [-4.268 – -0.306 s] and mean difference = -3.067, 95% CI [-5.141 - -0.993 s] respectively). However, the oxidative capacity index was not significantly different between climbing disciplines for the FDP or the EDC. Further, there were no significant between group differences in resting $m\dot{V}O_2$ for the FDP or the EDC.

Discussion

The major findings of this study were that, 1) the oxidative capacity index of both the FDP and the EDC was significantly greater in both climbing groups compared to the control group but, this test does not appear to distinguish between climbing disciplines; 2) there was a significantly greater MVC in climbers with a greater MVC in boulderers versus lead climbers. This was accompanied with no differences in ΔFAV between any climbing groups; 3) the FTI of intermittent contractions at an exercise to rest ratio of 10:3 s is beneficial for distinguishing climbers and non-climbers, but it is not a useful tool to distinguish between climbing disciplines; and 4) there were no significant between group differences in resting $m\dot{V}O_2$ in either the FDP or the EDC.

The current study found that the oxidative capacity index was significantly greater in all climbers compared to non-climbers, but there were no differences between climbing disciplines. Previous research has found that the oxidative capacity index has a moderate to strong relationship (R^2 = 0.52) to lead climbing performance (Fryer et al., 2016). However, as the oxidative capacity index could not discriminate between climbing disciplines, only control and climbers, it is likely that climbers, irrespective of discipline, have an improved forearm aerobic capacity. This heightened aerobic capacity may be caused by a combination of the prolonged period of time spent ascending in lead climbing, and the brief rest periods seen in bouldering. Time motion analysis has suggested that lead routes usually take between 2 – 7 min to complete and contraction time on each hold is ∽10 s (Michailov, 2014; Watts, 2004) and so there is a reliance on the forearm aerobic metabolism during the ascent. However, as an ascent in bouldering lasts ∽30 s and the rest time during hand transfers between holds is very short (approx. 0.6 s) (White & Olsen, 2010), there is a heightened need for rapid PCr re-synthesis. As such the ability to re-synthesis PCr is likely to be very important for bouldering performance. As PCr re-synthesis can only happen using energy which is aerobically derived (McCully et al., 1994), boulderers will also have a heightened oxidative capacity as evidenced in Table 2. Additionally, previous research (Fryer et al., 2016) has suggested that a possible mechanistic adaptation for an increase in oxidative capacity index in rock climbers could be an increase in $m\dot{V}O_2$, however this is not evidenced in the current study when assessments were made during resting conditions. It may be that the greater oxidative capacity index seen in climbers is caused by an increase in the ability to re-perfuse a muscle through a greater capillarization, vasodilation and increased blood flow. Future work should look to determine muscle perfusion, $m\dot{V}O_2$ and blood flow during varying intensities of forearm exercise.

Previously the FTI has been used as a performance marker to distinguish between climbing abilities (Fryer, Stoner, Dickson, et al., 2015; MacLeod et al., 2007; Philippe et al., 2011). Data from the current study suggests that although the FTI (at 40% MVC) can distinguish between climbers and non-climbers, it is not able to distinguish between climbing disciplines (Table 2). Boulderers have a significantly greater MVC compared to lead climbers, and lead climbers have a significantly greater time to exhaustion (when contracting at 40% MVC) than boulderers, and as such these values cancel each other out in the FTI equation [FTI = 0.4 x length of contraction (s) x force (N)]. It is unlikely that the low percentage of MVC (40%) used in the FTI affected the results as no differences have also been reported when the contraction was performed at 60% MVC (Kodejska et al., 2015). As such it may be that the FTI is not an appropriate measure and MVC/ΔFAV is a more sensitive marker for distinguishing between ability groups and disciplines within the sport.

Additionally, data from the current study supports the limited previous research suggesting that boulderers have a greater MVC and reduced endurance compared to both non-climbers (Macdonald & Callender, 2011) and lead climbers (Kodejska et al., 2015). However, a novel finding of this study is that both boulderers and lead climbers have a greater MVC/ΔFAV compared to non-climbers. Further, boulderers have a significantly greater MVC/ΔFAV than lead climbers. As FAV and ΔFAV was not significantly different between any groups, it could be that the greater MVC in boulderers compared to lead climbers is not due to hypertrophy but a chronic neural adaptation induced by several years of explosive training. Previously, boulderers have been shown to be more dynamic and explosive than lead climbers (White & Olsen, 2010) and have a greater rate of force development compared to lead climbers (Fanchini et al., 2013). Additionally explosive and dynamic training has been previously shown to increase the motor unit discharge rate (Aagaard, 2003). As such, the suggestion that a greater MVC and MVC/BW in boulderers may be caused by neural adaptions seems likely.

This study highlights the importance of the aerobic metabolism for both rock climbing performance and recovery between intense anaerobic bouts of forearm exercise. Additionally, the data presented could be used in future studies to help prescribe exercise intensities and help ascertain training targets in both disciplines. Additionally, it should be noted that there is a paucity of research using female climbers and this should be addressed in future works to improve our understanding of the sport and help determine training targets for this population.

Conclusion

To our knowledge this was the first study to assess 1) the oxidative capacity index, FAV and Δ FAV (post intermittent contraction to failure) of the dominant forearm in both boulderers and lead climbers, 2) oxygenation kinetics in a forearm extensor (the EDC), and 3) $m\dot{V}O_2$ in the FDP and EDC. Findings suggest that the greater MVC seen in boulderers compared to lead climbers and non-climbers may be due to neural adaptations and not hypertrophy. Additionally, both climbing groups have a greater oxidative capacity index than non-climbers suggesting a notable contribution from the aerobic metabolism. As such, irrespective of climbing discipline, trainers, coaches, and practitioners should consider forearm specific aerobic training to aid performance.

Conflict of Interest

No funding was received for the purposes of this study. The authors declare no conflicts of interest.

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