Title: Forearm muscle oxidative capacity predicts sport rock climbing performance

Running head: Oxidative capacity predicts rock climbing performance

Key words: Oxidative metabolism, microvascular adaptation, near infrared spectroscopy, haemodynamics

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Abstract

Introduction: Rock climbing performance, typically estimated using the red-point performance grade, is thought to be largely dependent on the endurance of the forearm flexor muscles. Recently, it was reported that forearm flexor endurance in elite climbers is independent of the ability to regulate conduit artery blood flow, suggesting that endurance is not primarily dependent on the ability of the brachial artery to deliver oxygen, but rather the ability perfuse and use oxygen in the muscle, i.e. skeletal muscle oxidative capacity. **Purpose:** The aim of the current study was to determine whether the oxidative capacity of the flexor digitorum profundus (FDP) predicts the best sport climbing red-point performance grade. **Methods:** Participants consisted of 46 young sport climbers with a range of abilities (6a+ to 8c+ French Sport). Using near infrared spectroscopy, oxidative capacity of the FDP was assessed by calculating the half-time for FDP tissue oxygen re-saturation (O_2HTR) following 3-5 min of ischemia. **Results:** A linear regression model, adjusted for age, sex, BMI and training experience (months) revealed that 1 s decrease in O_2HTR (i.e., improvement in oxidative capacity) was associated with an increase in the red-point grade by 0.65 (95% CI: 0.35-0.94, AdjR^2 = 0.53). **Conclusions:** Considering a performance grade of 0.4 separated the top 4 competitors in the 2015 International Federation Sport Climbing World Cup, these findings suggest that forearm flexor oxidative capacity is an important determinant of rock climbing performance. Measurement of forearm flexor oxidative capacity may serve as a novel and useful indicator of training status in sport rock climbers.

Introduction

Rock climbing performance, typically estimated using the red-point performance grade, has been suggested to be dependent on the endurance characteristics of the forearm skeletal muscles (14), particularly the flexor digitorum profundus (FDP) as it flexes the distal joint of fingers 2, 3, 4 and 5 (used in the open crimp position) (21). However, despite the emerging evidence suggesting that as a consequence of training, rock climbers undergo notable vascular and cellular adaptations in their forearms, the characteristics and importance of these adaptations in relation to performance remain relatively poorly understood (24).

Rock climbing involves exercising for prolonged periods of time (3-7 minutes), during which much of the time is spent contracting over 10% of MVC. As such, muscle blood flow will be insufficient to maintain cellular homeostasis (23) and the muscle will be exposed to regular periods of ischemia (24). It is expected that the endurance of the FDP (i.e. repeated bouts of MVC or near MVC) would be dependent on the ability to (i) deliver and (ii) use oxygen outside these periods of ischemia. Recently it has been reported that elite level rock climbers are able to not only de-oxygenate the FDP to a greater extent during intermittent handgrip exercise compared to non-climbers (10), but they were also able to re-oxygenate a greater amount of oxygen more quickly (12). This pattern has been seen in several studies where sport climbers were tested during both sustained and intermittent contractions to failure (10, 11, 17, 19). Interestingly, during the rest periods (3s) seen during intermittent handgrip tests (10s), there appears to be no differences between elite climbers and non-climbers in brachial artery diameter or blood velocity (11). Also, Thompson et al., (24) found that rock climbers had a significantly enhanced capillary filtration in the microvasculature compared to non-climbers, yet there were no differences in flow-mediated dilation between the groups. This suggests that the adaptations seen in elite climbers, which enable them to contract with a higher force and for a greater period of time, may be due to microvascular or cellular adaptations and not of the macro vascular (conduit artery).

The ability to rapidly perfuse oxygen in the muscle tissue and subsequent cellular use following ischemia may, therefore, be more important than solely delivery through the conduit artery. The increases in performance may be attributed to a range of microvascular or cellular adaptations enhancing the oxidative capacity of skeletal muscle. Skeletal muscle oxidative capacity which encompasses the delivery, perfusion and use of oxygen within the muscle has previously been shown to be related to sub-maximal (2, 16) and maximal exercise (2, 22). If oxidative capacity could predict rock climbing performance then it would provide further insight into the underlying muscle physiology of this unique group and help practitioners focus their training techniques on improving the oxidative metabolism of the forearm flexors. The aim of the current study was to determine whether oxidative capacity of the FDP predicts rock climbing performance ability (red-point performance grade).

Method

Participants

Forty-six young active sport climbers (described in Table 1) volunteered to participate in the study. All participants were non-smokers and were not taking any vascular-acting medications. Institutional ethics, which met the standard of the Journal and the Declaration of Helsinki of the World Medical Association, was granted before commencing recruitment or testing.

Procedures

All participants were asked not to consume food for 4 hours prior to testing and avoid caffeine and exercise for at least 12 hours. All testing sessions were conducted in an environmentally controlled exercise physiology laboratory. Upon reporting to the laboratory, each participant filled out forms for determination of health history, informed consent, demographic data, and self-reported red-point climbing ability using a method previously validated by Draper et al., (7). Finally, oxidative capacity was assessed using near infra-red spectroscopy (NIRS).

Self-reported climbing ability

The level of rock climbing ability is most commonly expressed in terms of the best ascent of a route within the last 6-12 months. Draper et al., (7) examined the validity of this method by asking twenty-nine competitive rock climbers of varying abilities to self-report their best on-sight performance before being asked to climb a competition route. The route increased in difficulty and the distance achieved by the climbers denoted the grade achieved, similar to that seen in competition. Despite minor over- and under-estimations in male and females respectively, there were no significant or meaningful differences between self-reported grade and the grade achieved. As such, this method of assessing rock climbing ability has been extensively used within the literature (4-6, 9-12).

Near infrared spectroscopy

Near-infrared spectroscopy was used to monitor changes in the oxygenation status of the FDP in the dominant arm. In accordance with previous research (19, 21) the FDP was assessed as it has been deemed to be the most important finger flexor for rock climbing performance. The FDP was located using the technique suggested by Schweizer et al., (21), where the thumb and the first finger were squeezed together; the flexor was then palpated to locate the middle of the muscle belly. A Portalite continuous-wave NIRS device (Artinis Medical Systems BV, Zetten, The Netherlands), sampling at 25Hz, was placed over the muscle belly of the FDP. As the forearm is a site with little fat storage (12), and rock climbers are characterized by a low body fat percentage (10, 14), the effects of excessive adipose tissue on the NIRS signal was considered negligible. The Portalite consists of three light emitting diodes, positioned 30mm, 35mm and 40mm from a single receiver, which transmit infrared light at twowavelengths (760nm and 850nm). A measure of tissue saturation index (TSI) was derived from the oxy-haemoglobin and total haemoglobin concentrations.

Oxidative capacity protocol

Oxidative capacity was estimated by calculating the oxygenation (TSI) half time to recovery (O_2HTR) using NIRS, a technique which has previously been validated against the standard measurement of phosphocreatine (PCr) recovery using magnetic spectroscopy (18). TSI is O_2Hb/ (O_2Hb/HHb) and is expressed as a percentage, as such it reflects oxidative capacity which is a combination of the oxygen delivery, perfusion and consumption within the muscle. Briefly, participants were fitted with a brachial artery tourniquet (Hokanson Inc, WA, USA) prior to being asked to lie down in a supine position for 20 minutes of quiet rest. During this time the NIRS optode was placed over the FDP in accordance with the manufacturers guidelines. A black cloth was placed over the optode to prevent any ambient light interfering with the signal. After 20 minutes of quiet rest, participants were asked to conduct light (∽10% maximal volitional contraction) handgrip dynamometry (HGD) exercise in order to activate the metabolism. Immediately following HGD exercise the tourniquet was inflated to a supra-maximal pressure (220mmHg) and sustained until the TSI signal plateaued at its lowest attainable value for ~ 30 sec, which generally occurred between minutes 3-5 of the occlusion. Following a stable plateau, the cuff was rapidly released and recovery values of TSI were obtained for 5-minutes. This was enough time to allow TSI to fully recover (a stable plateau for ~ 30 sec) in all individuals. As such a reduction in the O_2HTR (sec) is concomitant with an increase in skeletal muscle oxidative capacity.

Data analysis

In accordance with the Position Statement by the International Rock Climbing Research Association (IRCRA) (8), all performance grades were converted from French Sport to specific numerical values for all statistical analysis. Using the performance grade, the climbers were classified into upper and lower 50^{th} percentiles. Prior to analysis, all variables were assessed for heteroscedasticity by assessing the variance of the residuals, normal distribution using the Kolmogorov-Smirnov goodness-of-fit test, and equal variance using Levene's test. All variables were found to be homoscedastic, normally distributed and had equal variance. Linear regression was performed to assess the predictive capability of forearm skeletal muscle oxidative capacity (independent variable) for self-reported red-point sport climbing grade (dependent variable), with and without adjustment for covariates. Odds ratios (ORs) and 95% confidence intervals were estimated using logistic regression models to evaluate the associations of forearm skeletal muscle oxidative capacity with upper 50th percentile performance grade, with and without adjustment for covariates. The covariates included age, sex and BMI. Experience rock climbing (Climbing time, expressed in months) was included in additional models since it was considered on the causal pathway and may have spuriously attenuated the estimates of association. All tests were two-sided, with type I error rate fixed at 0.05. All analysis were performed using Statistical Package for Social Sciences (SPSS, IBM, Version 21).

Results

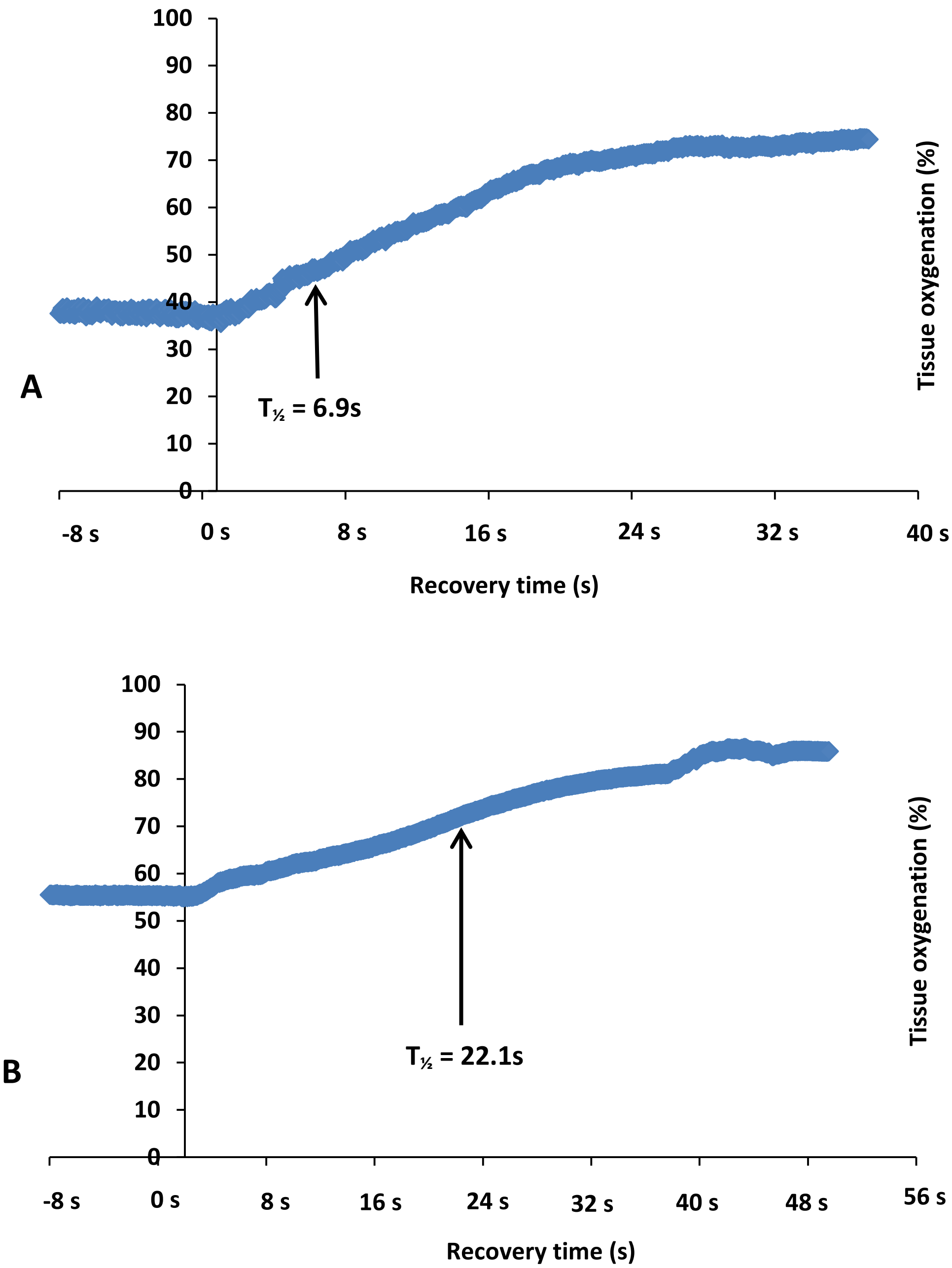

Figure 1 Time to half recovery (O_2HTR) examples of a high level sport climber (A = 8c+ French, 6.9s O_2HTR) and a low level sport climber (B = 6a+ French, 22.1s O_2HTR).

The characteristics of the rock climbers are presented in Table 1. The climbers used in the analysis had a best six-month red-point grade (sport) which ranged from 6a+ to 8c+ French Sport (Ewbank 17 to 32). Climbers in the top 50th percentile were all male and had a lower BMI and a quicker O_2HTR.

Table 1. Characteristics of rock climbers according to performance status.

	Total (n=46)		Percentile <50 (n=23)		Percentile > 50 (n=23)		
	X	SD	X	SD	X	SD	*P*
Age (yrs)	30.8	(7.3)	30.4	(7.0)	31.2	(7.0)	*0.708*
Female (%)	24		50		0.0		*0.000*
Weight (Kk)	67.0	(8.6)	63.9	(6.9)	70.0	(6.9)	*0.015*
Height (cm)	172.9	(7.3)	171.5	(6.5)	174.2	(6.5)	*0.216*
BMI (kg/m^2)	22.3	(1.9)	21.6	(1.9)	23.1	(1.9)	*0.009*
Experience (m)	99.7	(81.7)	105.3	(83.3)	94.1	(83.3)	*0.648*
Performance	18.6	(3.3)	15.9	(2.0)	21.3	(2.0)	*0.000*
O_2HTR	7.6	(2.4)	8.3	(2.2)	6.9	(2.2)	*0.049*

BMI= body mass index; experience= number of months experience rock climbing; O_2HTR= oxygenation half-time to recovery (oxidative capacity); performance = IRCRA scale

Table 2. Linear and logistic regression models: association between forearm oxidative capacity and climbing capacity.

		β	LCI	UCI	*P*	R^2	AdjR^2
Linear Regression Model							
Model 1:	Unadjusted	-0.67	-1.04	-0.30	*0.001*	0.24	0.22
Model 2:	Age, sex, BMI	-0.62	-0.92	-0.33	*<0.001*	0.56	0.52
Model 3:	Age, sex, BMI, experience	-0.65	-0.94	-0.35	*<0.001*	0.57	0.53
		OR	LCI	UCI	*P*		
Logistic Regression Model							
Model 1:	Unadjusted	1.34	0.99	1.81	*0.600*		
Model 2:	Age, sex, BMI	1.54	1.00	2.35	*0.048*		
Model 3:	Age, sex, BMI, experience	1.58	1.00	2.49	*0.050*		

β = beta, regression equation; BMI= body mass index; experience= number of months experience rock climbing; LCI= lower confidence interval (95%); OR= odds ratio; UCI= upper confidence interval (95

Linear regression analysis (Table 2) revealed that skeletal muscle oxidative capacity of the FDP is significantly associated with the highest self-reported red-point sport climbing grade. Following adjustment for covariates, a 1s decrease in O_2HTR (i.e. improvement in oxidative capacity) was associated with an increase of 0.65 (95% CI: 0.35-0.94) of a red-point grade (IRCRA). Logistic regression analysis confirmed the linear regressions models; after adjustments for covariates, climbers with a quicker O_2HTR were 58% (95% CI: 1.00-2.49) more likely to be in the top 50th percentile for climbing performance.

Discussion

To our knowledge, this was the first study to assess local musculature oxidative capacity in a group of rock climbers. A 1s decrease in the O_2HTR (i.e., improvement in oxidative capacity) was associated with an increase of 0.65 (IRCRA) in red-point grade. Considering a performance grade of 0.4 separated the top 4 competitors in the 2015 International Federation Sport Climbing World Cup, this finding suggests that forearm flexor oxidative capacity is an important determinant of rock climbing performance, and may be used as a novel training target.

Early research investigating predictors of rock climbing performance placed a large emphasis on anthropometric characteristics (14, 15, 26). This was quickly followed by an influx of research assessing whether climbing was characterized by large contributions from the anaerobic or aerobic metabolism (1, 3). However, it became apparent that assessing whole body $\dot{V}O_2$ was not sensitive enough to predict performance, as potential adaptations in the small musculature of the forearms were masked by whole body $\dot{V}O_2$ assessments at the mouth. As such, recent studies focused on forearm hemodynamic kinetics to help better understand the physiology of the most dominant muscle group used the forearm flexors. It was reported that elite rock climbers are able to de-oxygenate their forearm flexors more than non-elite climbers, and this finding was not explained by the ability to regulate conduit artery blood flow (11).

Given the relatively small amount of activated skeletal muscle in the forearms, the lack of relationship between blood flow and performance may not be surprising. The alternative explanation, which is that elite climbers have a greater oxidative capacity in the forearms as they are more proficient at perfusing and utilizing oxygen, is supported by the current study (Table 2). Previously HIT work has been shown to increase the reliance on oxidative muscle metabolism during the latter stages of maximal exercise, as a reduction in ATP has been generated through anaerobic processes matched with a 10-fold increase in the rate glycogen was degraded to blood lactate acid (13). As rock climbing involves high-intensity intermittent exercise (∽3-7 min per ascent) it is likely to cause adaptations in the structure and function of the forearm muscles which would increase oxidative capacity, and as such can help to in part explain, and predict rock climbing performance. This enhanced oxidative capacity is likely due to greater perfusion of oxygen to the muscle via an increased capillary density and increased venule density leading to an enhanced venous return, which would consequently improve metabolic waste clearance within the muscle.

The current study provides new insightful information regarding the importance of local muscular adaptations for performance in high level rock climbers; however, several limitations should be acknowledged. 1) This study assessed oxidative capacity which provides a complete representation of capacity to delivery and utilize oxygen within the muscle. Subsequent studies should use NIRS technology to independently assess mitochondrial oxidative capacity (20), muscle blood flow (25) and muscle oxygen consumption (20) to provide a more in-depth understanding of the adaptations in the FDP. 2) Our logistic regression model was limited by the exclusion of females in the upper 50^{th} percentile group, but not in the lower 50^{th} percentile. While the linear regression model does confirm the association between oxidative capacity and rock climbing performance ability, further study is warranted to determine optimal training interventions to improve oxidative capacity.

Conclusion

To the best of our knowledge, this was the first study to assess local musculature oxidative capacity in a group of rock climbers. Findings suggest that forearm flexor oxidative capacity is an important determinant of rock climbing performance. Measurement of forearm flexor oxidative capacity may serve as a novel and useful indicator of training status in sport rock climbers.

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Figure and Table Legends

Figure 1 Time to half recovery (O_2HTR) examples of a high level sport climber (A = 8c+ French) and a low level sport climber (B = 6a+ French).

Table 1. Characteristics of rock climbers according to performance status (IRCRA).

BMI= body mass index; experience= number of months experience rock climbing; O_2HTR= oxygenation half-time to recovery (oxidative capacity)

Table 2. Linear and logistic regression models: association between forearm oxidative capacity and climbing capacity.

β = beta, regression equation; BMI= body mass index; experience= number of months experience rock climbing; LCI= lower confidence interval (95%); OR= odds ratio; UCI= upper confidence interval (95%)