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Title Page

Title: Forearm muscle oxidative capacity index predicts sport rock climbing performance

Running head: Oxidative capacity index predicts rock climbing performance

Key words: Oxidative capacity, microvascular adaptation, near infrared spectroscopy

List of abbreviations:

CI	……….	Confidence interval
FDP	……….	Flexor digitorum profundus
HHb	……….	Deoxy-haemoglobin
IRCRA	……….	International rock climbing research association
NIRS	……….	Near infrared spectroscopy
O_2THR	……….	Oxygen time to half recovery
O_2Hb	……….	Oxyhaemoglobin
PCr	……….	Phosphocreatine
tHb	……….	Total haemoglobin
TSI	……….	Tissue saturation index
$\dot{V}O_{2max}$	……….	Maximal oxygen consumption

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Abstract: 211 words

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Abstract

Rock-climbing performance is largely dependent on the endurance of the forearm flexors. Recently, it was reported that forearm flexor endurance in elite climbers is independent of the ability to regulate conduit artery (brachial) blood flow, suggesting that endurance is not primarily dependent on the ability of the brachial artery to deliver oxygen, but rather the ability of the muscle to perfuse and use oxygen, i.e. skeletal muscle oxidative capacity. **Purpose**: The aim of the study was to determine whether an index of oxidative capacity in the flexor digitorum profundus (FDP) predicts the best sport climbing red-point grade within the last 6 months. Participants consisted of 46 sport climbers with a range of abilities. **Methods:** Using near infrared spectroscopy, the oxidative capacity index of the FDP was assessed by calculating the half-time for tissue oxygen re-saturation (O_2HTR) following 3-5 min of ischemia. **Results:** Linear regression, adjusted for age, sex, BMI and training experience, revealed a 1s decrease in O_2HTR was associated with an increase in red-point grade by 0.65 (95% CI: 0.35-0.94, AdjR^2 = 0.53). **Conclusions:** Considering a 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 index is an important determinant of rock climbing performance.

Introduction

Rock climbing performance has been suggested to be dependent on the endurance characteristics of the forearm skeletal muscles (Watts et al. 1993), particularly the flexor digitorum profundus (FDP) as it bends the distal joint of fingers 2, 3, 4 and 5 (used in the open crimp position) (Philippe et al. 2011). In turn, the endurance of the FDP would be expected to be dependent on the ability to (i) deliver and (ii) use oxygen (Fryer et al. 2015b). However, a recent study reported the ability to deliver oxygen at the conduit artery (brachial) level, during contractions to failure does not predict rock climbing performance (Fryer et al. 2015c), suggesting that the ability to deliver and use oxygen in the muscle (oxidative capacity) may be a more important determinant of performance. If a simple test to assess an index of oxidative capacity could in part predict rock climbing performance then it would help practitioners focus their training techniques on improving the oxidative metabolism of the forearm flexors. As such the aim of the current study was to determine whether a simple measure of the oxidative capacity index in the FDP may, in part, predict rock climbing ability estimated using the red-point performance grade. Specifically it was hypothesized that a higher oxidative capacity index, estimated from near infrared spectroscopy, would be associated with a higher self-reported red-point grade.

Method

Participants

Forty-six young (36 male, 10 female) 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. Data from this study comes from the high performance international rock climbing research group C-HIPPER.

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 self-report method previously validated by Draper et al. (2011b). Finally, oxidative capacity index 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. (2011b) 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, the self-report method has been used for on-sight and red-point performance extensively within the literature for both red-point and on-sight (Dickson et al. 2012a; Dickson et al. 2012b; Draper et al. 2011a; Fryer et al. 2012; Fryer et al. 2015a; Fryer et al. 2015b; Fryer et al. 2015c). The current study used a self-reported best red-point grade achieved in the 6 months prior to laboratory testing. As the red-point style of ascent allows for unlimited technical information from coaches and peers, as well as limitless practice attempts of a route before a clean (no falls or weighting the rope) completion, it was felt that the red-point style of ascent provided the best description of the climbers maximal performance, without the psychological and technical challenges that are associated with an on-sight ascent of a novel route.

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 (Philippe et al. 2011; Schweizer and Hudek 2011) the FDP was assessed as it has been deemed to be the most important finger flexor for rock climbing performance. Although previous research has shown that different sections of a muscle have different deoxygenation responses (Koga et al. 2007), the authors of the current study have made every attempt to ensure consistent probe placement between participants. The FDP was located by a chartered physiotherapist using the technique suggested by the rock climbing specialist finger surgeons Schweizer and Hudek (2011), 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. Skinfold measurements which incorporate skin and adipose fat were taken from under the optode on the FDP, and are reported in Table 1. As the values are notably less than the ≥6.4mm which has been shown to significantly affect the NIRS signal quality (Van Beekvelt et al. 2001a), the effects of excessive adipose tissue on the NIRS signal in the current study were considered negligible. The Portalite consists of three light emitting diodes, positioned 30mm, 35mm and 40mm from a single receiver, which transmit infrared light at two-wavelengths (760nm and 850nm). A measure of tissue saturation index (TSI) was derived from the oxy-haemoglobin (O_2Hb) and deoxy-haemoglobin (HHb) concentrations, the sum of which is total haemoglobin concentrations (tHb). It is important to note that, due to the similarity in spectra, NIRS cannot differentiate between haemoglobin and myoglobin and as such provides a reading that incorporates both. For clarity and convenience, the combination of both haemoglobin and myoglobin are referred to as haemoglobin in this paper

Oxidative capacity index protocol

Oxidative capacity index 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 (McCully et al. 1994). Expressed as a percentage, TSI is calculated as O_2Hb/(O_2Hb+HHb)x100 and reflects tissue oxygen saturation which is determined by a combination of 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. A standardized 30s plateau in TSI was chosen rather than a standardized time of 5 minutes so that the buildup of metabolic waste was consistent across individual participants. 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 in all individuals. A reduction in the O_2HTR (sec) is concomitant with an increase in skeletal muscle oxidative capacity index.

Data analysis

In accordance with the Position Statement by the International Rock Climbing Research Association (IRCRA) (Draper et al. 2016), 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 50th 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 index (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 50^{th} 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

------------Insert Figure 1 near here-------------

(Scatter plot)

The anthropometric and demographic 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 50^{th} percentile were all male and had a lower BMI and a quicker O_2HTR.

------------Insert Table 1 near here-------------

------------Insert Table 2 near here-------------

------------Insert Figure 2 near here-------------

(Example graph with ΔO_2Hb, ΔHHb, and TSI for high and low performer)

Linear regression analysis (Table 2) revealed that skeletal muscle oxidative capacity index of the FDP is significantly associated with the highest self-reported red-point rock climbing grade. Following adjustment for covariates, a 1s decrease in O_2HTR (i.e. improvement in oxidative capacity index) 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 attempt to assess the relationship between forearm oxidative capacity index and rock climbing performance. Forearm oxidative capacity index was estimated by calculating the O_2HTR using NIRS (McCully et al. 1994). A 1s decrease in the O_2HTR (i.e., an improvement in oxidative capacity index) was associated with an increase of 0.65 IRCRA (0.72 French sport) in red-point grade. Considering a performance grade of 0.4 (0.44 French sport) separated the top 4 competitors in the 2015 International Federation Sport Climbing World Cup, this finding suggests that although forearm flexor O_2HTR does not fully explain all the variance in performance, it is 1) clearly an important associate, and 2) this NIRS-based index may be used as a simple training tool.

Early research investigating rock climbing performance aimed to determine whether climbing was characterized by large contributions from the anaerobic or aerobic metabolism (Bertuzzi et al. 2007; de Geus et al. 2006). 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 have focused on forearm hemodynamic kinetics to help better understand the physiology of the most dominant muscle group - the forearm flexors. It was reported that elite rock climbers are able to de-oxygenate their forearm flexors to a greater extent than non-elite climbers, and this finding was not explained by the ability to regulate conduit artery (brachial) blood flow (Fryer et al. 2015c). Given the relatively small amount of activated skeletal muscle in the forearms, the lack of relationship between conduit artery (brachial) blood flow and performance is not surprising and supports previous - albeit more indirect - findings. The earlier studies reported that forearm vascular conductance is higher in trained rock climbers compared to a control group after both sustained and intermittent handgrip exercise, as well as post 10 min arterial occlusion (Ferguson and Brown 1997). However, it should be acknowledged that these previous studies have investigated conduit artery or whole forearm blood flow, and further research is warranted to determine the relative importance of skeletal muscle microvascular perfusion and blood flow to rock climbing performance.

Self-reported 6-month red-point climbing ability provides a valid measure of a climber's current ability (Draper et al. 2011a). As expected, an individual's climbing ability is multifactorial, made up of a unique combination of physiological, psychological and technical components (Gáspari et al. 2015; Gerbert and Werner 2000). While current climbing literature is not exhaustive, there are other factors which have been shown to influence and explain variance in performance such as handgrip strength (Baláš et al. 2012), climber flexibility (Brent et al. 2009), and improved exercise economy (Baláš et al. 2014). Further, these physical attributes are accompanied by technical and psychological factors, including but not limited to; an increase in efficiency of footwork (Baláš et al. 2014), capacity to produce stable movement paths (Cordier et al. 1993) and differences in the perception of affordances (Boschker et al. 2002). Thus, while forearm flexor O_2HTR is clearly an important factor, climbing ability is multi-faceted, and it should not be expected that one factor would fully explain all the variance in performance.

Several limitations should be acknowledged. 1) While investigation of the physiological mechanisms explaining rock climbing performance was beyond the scope of this paper, the association between O_2HTR and performance does support the importance of forearm oxidative capacity. Subsequent studies are warranted to decompose the pathways explaining forearm oxidative capacity, and may use NIRS technology to independently assess skeletal muscle: blood flow (Van Beekvelt et al. 2001b), oxygen consumption (Ryan et al. 2013), and mitochondrial respiratory capacity (Ryan et al. 2013), 2) In addition to O_2HTR, other key performance indicators of fatigue and exercise tolerance such as critical power (Jones et al. 2010; Poole and Jones 2012), would provide a more in-depth understanding of the physiological mechanisms responsible for forearm endurance and rock climbing performance. 3) Only the red-point sport performance grade was used to assess performance. Other ascent styles and climbing disciplines should be investigated to confirm the predictive utility of O_2HTR. 4) Lastly, the logistic regression model was limited by the exclusion of females in the upper 50th percentile group. While the linear regression model does confirm the association between O_2HTR and rock climbing performance ability, further study is warranted to determine whether the prediction equation should consider sex.

Conclusion

To the best of our knowledge, this was the first study to assess local musculature oxidative capacity using a NIRS-derived index in a heterogeneous group of rock climbers. Findings suggest that although the forearm flexor oxidative capacity index does not explain all variance in red-point performance, it is an important associate of performance. Measurement of forearm flexor oxidative capacity index may serve as a simple and valuable indicator of training status in sport rock climbers.

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

			Percentile				
	Total (n=46)		<50 (n=23)		> 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 (kg)	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*
Skin fold (mm)	1.8	(0.6)	1.9	(0.7)	1.8	(0.6)	*0.564*
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 index); performance = IRCRA scale

Table 2. Linear and logistic regression models: association between forearm oxidative capacity index 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%)

Figure Legends

Figure 1. Linear regression model for O_2THR (oxidative capacity index) and highest 6month self reported red-point grade (International Rock Climbing Research Association grade scale).

Figure 2. Example traces of the TSI (A), ΔO_2Hb (B) and ΔHHb (C) responses pre, during and post occlusion for high (>50th percentile) and low (<50th percentile) rock climbers.

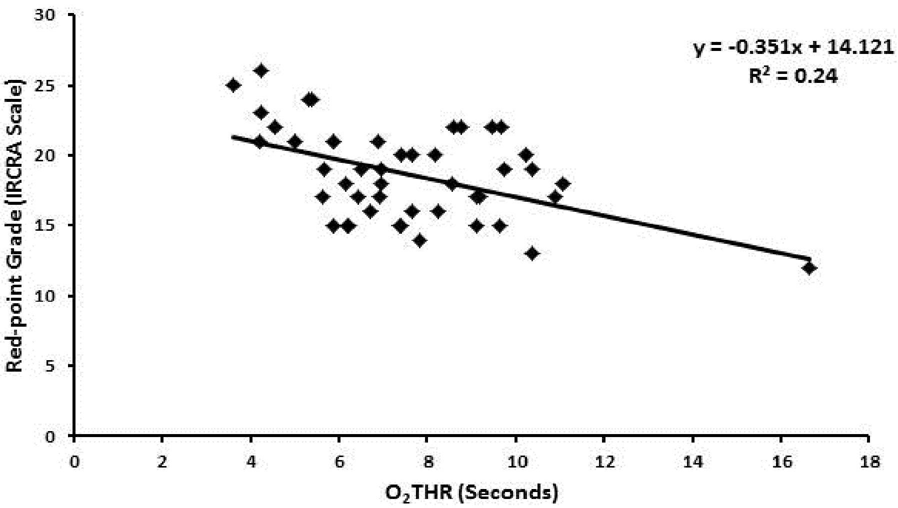

Figure 1

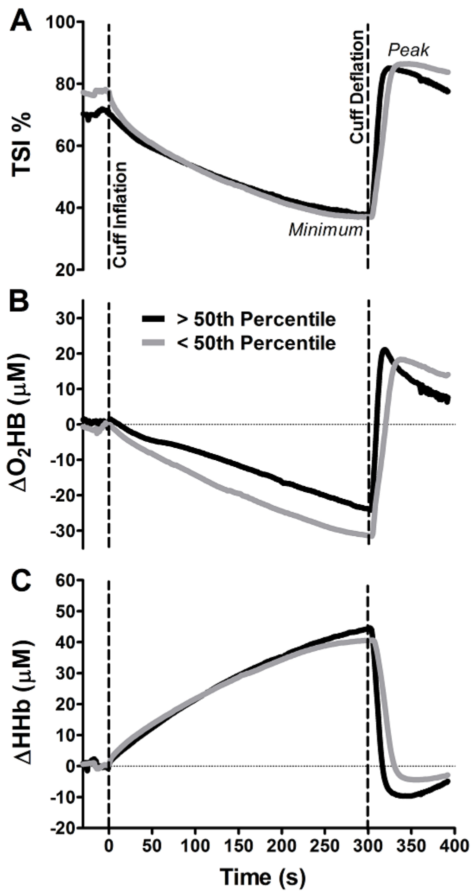

Figure 2