TITLE
Hemodynamic and cardiorespiratory predictors of sport rock climbing performance

BRIEF RUNNING HEAD
Predictors of sport climbing

ABSTRACT

Rock climbing performance has been suggested to involve a notable contribution from the aerobic metabolism. Previously it has been shown that forearm oxygenation kinetics can be used to distinguish ability groups and predict red-point sport climbing performance. Currently it is not known if forearm oxygenation kinetics, or a sport specific assessment of cardiorespiratory fitness best predicts sport rock climbing performance. The aim of the study was to determine whether forearm oxidative capacity index, maximal de-oxygenation (Δ score) during a treadwall $\dot{V}O_{2peak}$ test, treadwall $\dot{V}O_{2peak}$, or running $\dot{V}O_{2max}$ best predicts self-reported sport climbing performance. Twenty-one male sport rock climbers completed a treadwall $\dot{V}O_{2peak}$, running $\dot{V}O_{2max}$ and an assessment of near infrared spectroscopy derived oxidative capacity index. Linear regression, adjusted for age and experience (years), revealed that forearm oxidative capacity index, treadwall maximal de-oxygenation (Δ) and treadwall $\dot{V}O_{2peak}$ all significantly predicted self-reported red-point sport climbing ability (Adj R^2 =-0.398; -0.255; 0.374 respectively), whereas treadmill running $\dot{V}O_{2max}$ did not (Adj R^2 =0.-0.052). Additionally, multiple regression suggested that the combined significant aerobic predictors accounted for 67% of the variance in red-point climbing ability. Findings suggest that training for sport rock climbing performance should look to incorporate modalities which focus on 1) improving local forearm aerobic capacity, and 2) improving whole body aerobic capacity using sport-specific apparatus such as treadwalls.

KEY WORDS

Oxidative capacity, muscle blood flow, muscle specificity, sport specific training

INTRODUCTION

Rock climbing is a complex multifaceted sport and as such it is difficult to examine the physiological determinants of performance while maintaining ecological validity. Individual climbers excel or fail at particular types of moves and routes due to their varying anthropometric compositions and individual strengths in the sport. As such there is often no definitive sequence to a route and climbers ascend in a variety of ways to overcome the crux (hardest section on a route). Therefore, understanding the physiological underpinnings of the sport is difficult.

Early research assessed components of performance in isolation, commonly quantifying body composition and anthropometric characteristics, recognizing them as potentially important determinants of sport climbing performance (15, 34, 35). However, the importance of both the whole body aerobic metabolism and cardiorespiratory fitness in relation to performance remains relatively unknown. Previous assessments of whole body aerobic capacity ($\dot{V}O_{2max}$) have either been performed using treadmill running, which lacks ecological validity, or a treadwall with a protocol which lacked specificity to rock climbing (16). Compounding the problem further, the contemporary style of sport climbing has evolved in recent years and routes have become increasingly steep and overhanging resulting in a heightened need for high levels of upper body finger strength (6). As such, it is possible that a variety of determinants of climbing performance have also changed. Having a low body fat percentage and high lean muscle mass would still be of paramount importance in modern day sport climbing, but it has become less clear how important $\dot{V}O_{2max}$ is, given the fact that the small muscle mass of the forearms are the predominant working muscle.

Following the increased reliance on the small musculature of the forearms (31), assessments of haemodynamic kinetics in the forearm flexors (flexor digitorum profundus [FDP]) became a focal point for performance related research. Authors have used near infrared spectroscopy (NIRS) to distinguish ability group differences (intermediate, advanced and elite climbers) in maximal de-oxygenation during sustained (21) and intermittent (20) contractions, as well as assessing re-oxygenation after exhaustive finger flexor exercise (open crimp) (19). Although assessments of haemodynamic kinetics have been able to distinguish between ability groups, and in part predict performance (19), it is currently not known whether maximal de-oxygenation during a treadwall climb to failure, a NIRS derived oxidative capacity index or treadwall $\dot{V}O_{2peak}$ best predicts performance. As such the aim of the current study was to assess 1) how much variance in red-point performance can be explained by forearm oxidative capacity index, treadwall $\dot{V}O_{2peak}$, maximal forearm de-oxygenation during treadwall climbing and treadmill $\dot{V}O_{2max}$, and 2) what is the combined contribution of any significant aerobic predictors to red-point performance. Specifically it was hypothesized that either the NIRS derived oxidative capacity index, maximal de-oxygenation during a maximal treadwall test or treadwall $\dot{V}O_{2peak}$ would best predict red-point sport climbing performance.

METHODS

Experimental approach to the problem

The use of an automated revolving treadwall which had three routes varying in difficulty (for different ability level climbers), and could have the gradient/angle of wall altered, enabled the authors to create a sport specific stress which could be used to measure the maximal whole body cardiorespiratory response ($\dot{V}O_{2peak}$), as well as determining a forearm muscle specific measure of the oxygenation response during exercise (maximal de-oxygenation in the forearm (FDP) during the treadwall test). In addition, to these measures it was important to independently determine the aerobic capacity of the forearms. As such a non-invasive NIRS derived assessment oxidative capacity index (time to half recovery of the tissue saturation index %) of the FDP as described by (27) was used. The FDP was chosen because it has been suggested to be the most important flexor for climbing (28).

Subjects

The current study uses data from the C-HIPPER project, a European group of researchers focusing on furthering the mechanistic and performance related aspects of rock climbing. For the current study 21 male sport rock climbers volunteered to take part (descriptive data presented in Table 1). Climbers had a best 6-month red-point grade (sport) which ranged from 6a+ to 8a+ French Sport (IRCRA 12 to 24). All subjects described in Table 1 were healthy, non-smokers and were not taking any vascular acting medications. Institutional ethics which met the standard of the World Medical Association and the Declaration of Helsinki was granted prior to recruitment and testing. Before individual testing all subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Table 1. Mean (SD and Range) Anthropometric and demographic information for all sport climbers (n= 21).

	Mean	**SD**
Age (yrs)	32.4	6.9
Height (cm)	172.9	7.1
Mass (kg)	67.9	5.9
Forearm fat (g)	325.4	474.9
		Range
Best 6-month red-point grade (French)	7b+	7a-8a+
Best 6-month on-sight grade (French)	7a+	6c-7c

Forearm fat determined using DXA scanning.

Procedures

All subjects were asked not to consume food 4 hours prior to testing and to avoid caffeine and exercise for a minimum of 12 hours. Testing sessions were conducted in environmentally controlled laboratories. Subjects visited the laboratories on two occasions separated by at least 3, but no more than 7 days. During visit one subjects completed forms for the determination of informed consent, health history, demographic data, and self-reported sport rock climbing ability utilizing methods previously validated by

(11). This was followed by a maximal treadwall test to determine both $\dot{V}O_{2peak}$ and maximal de-oxygenation (Δ) of the forearm flexors. On the second visit subjects completed an assessment of NIRS derived oxidative capacity index in the dominant forearm flexor (FDP). Thirty minutes after the oxidative capacity test, subjects completed a treadmill $\dot{V}O_{2max}$.

Self-reported climbing ability

Rock climbing ability is most commonly expressed in terms of the best self-reported ascent of a route within the last 6-12 months. Draper et al., (13) proposed a 3:3:3 rule for reporting climbing grades in research: this is the climbers' highest red-point grade for which they have completed 3 successful ascents on 3 different routes (at the grade) within the previous 3 months. Data in the current study was collected prior to this guidance, a 3:3:6 ratio was used. However, the 6 month reported grade may be less susceptible to short term variation in training and climbing conditions. Recent discussion of an expert panel at the International Rock Climbing Research Association Congress (Colorado, August 2016), support these findings, and the practicality of 3:3:6 reporting. Additionally, Draper et al., (11) examined the validity of the self-report method by asking 29 competitive rock climbers of varying abilities to self-report their best on-sight performance before being asked to climb a competition style route. The route increased in difficulty and the distance achieved by the climbers denoted the grade achieved; a style 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. 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 this style of ascent would have demanded maximum physical effort, and would have minimized (but not removed) much of the influence from the technical and psychological aspects from the performance.

Near infrared spectroscopy

Near infrared spectroscopy was used to monitor changes in the oxygenation status of the FDP in the dominant flexor. The FDP was located by drawing a line on the anterior side of the forearm from the epicondyle of the humerus to the base of the carpus (lunate) proximal to the ring finger. The NIRS probe was placed 33% distal to the epicondyle of the humerus. 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 and rock climbers are characterized by a low body fat percentage, the effects of excessive adipose tissue on the NIRS signal were likely to be negligible. The Portalite consists of three light emitting diodes positioned 30 mm, 35 mm and 40 mm from a single receiver, which transmits infrared light at two-wavelengths (760 nm and 850 nm). 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 should be noted that NIRS cannot differentiate between myoglobin and haemoglobin and for clarity the combined are referred to as haemoglobin in this article. NIRS was used to assess the percentage TSI during two different tests in the current study, 1) during assessments of maximal de-oxygenation during a maximal treadwall test, and 2) during the assessment of oxidative capacity index.

Cardiorespiratory fitness

Cardiorespiratory fitness was determined by assessing oxygen uptake from maximal tests on a treadmill and treadwall. Specifically, for determination of $\dot{V}O_{2max}$ an incremental running test to volitional fatigue on a treadmill (Mercury LT med, HP Cosmos®, Germany) was used athlete led protocol (12). Briefly, subjects began running at 8 km/hr, speed increased by 1 km/hr every minute until maximal running speed was attained; after this point gradient increased by 1% every minute until the test end point. The test end point was either volitional exhaustion, an increase in gradient without a concomitant increase in $\dot{V}O_2$, or test termination if deemed necessary by the attending physician.

To determine treadwall $\dot{V}O_{2peak}$, an incremental rock climbing test (schematic presented in Figure 1) on a treadwall ergometer (Crestville Holdings, Sydney, Australia) fitted with artificial rock hand/foot holds was used. The belt speed of the ergometer was calibrated before each trial and monitored by continuous digital output that indicated the speed (12 m/min). Rock climbers were split into ability groups prior to testing, following the rationale of España-Romero et al. (15), based on their on-sight ability grade: intermediate ability ≤f6b; advanced ability from f6b+ to f7a+; and expert ability ≥f7b. The treadwall protocol was altered for each ability group via manipulation of the route ascended and the starting angle to ensure volitional exhaustion was obtained between 6 and 12 minutes, and therefore ensuring that participant attained $\dot{V}O_{2peak}$ during the incremental climbing exercise test (1, 2, 23, 29). The climbing trials were made different by manipulating the starting angles and ascending a different route (different hand a foot holds). The three routes were distinguished by the colour of the hand holds (a black and a white route). Briefly, the intermediate group climbed white holds for hands and all holds for feet (white and black holds). The advanced ability group climbed the white route only, and the expert group climbed the black route only. With regards to starting angles, the intermediate and advanced ability climbers began their treadwall test at 86°, and the expert group started at 92°. Following the start of the tests the angle further increased to 98°, 102° and 106°. Four minutes were spent climbing at the angles 86° and 92°, whereas two minutes were spent climbing at 98°, 102° and 106° (until exhaustion or volitional failure) for the intermediate and advance ability climbers. Whereas for the expert climbers, four minutes were spent at the angles 92° and 98º followed by two minutes 102° and 106° (until exhaustion or volitional failure).

Oxygen uptake, for both the treadmill and treadwall, was measured using a portable breath-by-breath expired air analyzer ($K4b^{2}$, Cosmed, Rome, Italy) weighing 1.5kg. Data were transferred continuously via telemetry to a portable laptop. Breath by breath data were recorded continuously pre, during and post running and climbing. Breath-by-breath data were averaged over 10 s intervals and exported to Excel and SPSS for final data analysis.

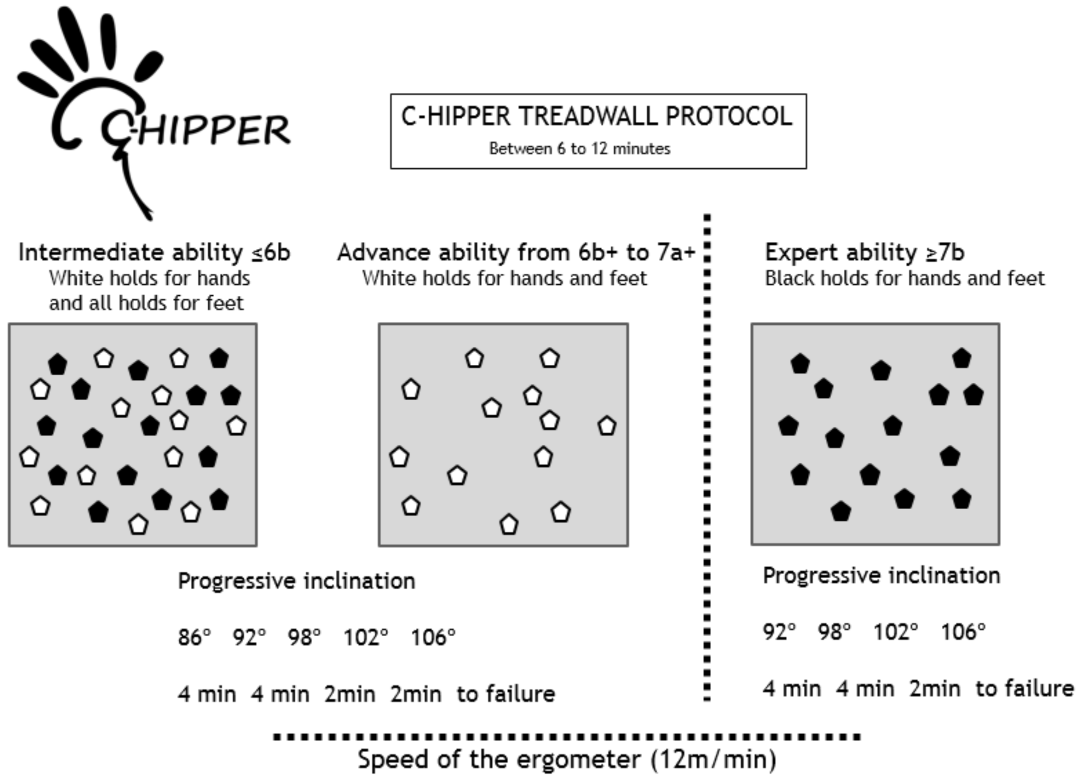

Figure 1 Schematic representation of the treadwall protocol used to determine $\dot{V}O_{2peak}$.

Oxidative capacity index

Oxidative capacity index was estimated by calculating the oxygenation 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 (27). Expressed as a percentage, TSI is calculated as (O_2Hb/(O_2Hb+HHb)) x100 and reflects the oxidative capacity index which is comprised of a combination of oxygen delivery, perfusion and consumption within the muscle. Briefly, subjects 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 manufacturer’s guidelines. A black cloth was placed over the optode to prevent any ambient light interfering with the signal. After 20 minutes of quiet rest, subjects 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 (230 mmHg) and sustained until the TSI signal plateaued at its lowest attainable value for ~30 seconds, which generally occurred between minutes 3-5 of the occlusion. A standardized 30 second plateau in TSI was chosen rather than a standardized time of 5 minutes occlusion so that the buildup of metabolic waste was consistent across individual subjects. 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 the 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) (14), performance grades were converted from French Sport to specific numerical values for all statistical analysis. All data were found to be normally distributed, homoscedastic and had equal variance. Prior to any $\dot{V}O_2$ analysis data was screened for any spurious breaths. To examine the extent to which the physiological responses (oxidative capacity index, treadwall $\dot{V}O_{2peak}$, treadwall de-oxygenation and treadmill $\dot{V}O_{2max}$) predicted self-reported red-point climbing performance, a series of linear regression analyses were performed. Physiological responses were entered into separate models as independent variables both with and without adjustment for the covariates age and experience (years climbing). Age was chosen as it has previously been shown to effect cardio-metabolic and vascular function (26); and climbing experience was selected as it is considered on a causal pathway and may have spuriously attenuated the estimates of association (22). The alpha level of significance was set at 0.05. All analyses were performed using Statistical Package for Social Sciences (SPSS, IBM, Version 21).

RESULTS

Anthropometric and demographic characteristics of all rock climbers in the current study are presented in Table 1. Subjects had a best 6-month red-point grade (sport) which ranged from 6a+ to 8a+ French Sport (IRCRA 12 to 24).

Table 2. Linear regression models: association between O_2THR (oxidative capacity index assessed using NIRS), maximal de-saturation during treadwall performance, treadwall $\dot{V}O_{2peak}$, treadmill $\dot{V}O_{2max}$ and red-point climbing ability

Independent variable	Linear Regression Models		β	LCI	UCI	P	R^2	AdjR^2
O2THR(s)	Model 1:	Unadjusted	-0.659	-0.946	-0.232	0.003	-0.434	-0.398
	Model 2:	Age	-0.750	-1.069	-0.274	0.003	-0.470	-0.400
	Model 3	Years climbing	-0.679	-1.001	-0.213	0.005	-0.437	-0.362
Max Δ de-saturation treadwall (TSI%)	Model 1:	Unadjusted	-0.549	-2.342	-0.207	0.022	0.301	0.255
	Model 2:	Age	-0.498	-2.292	-0.019	0.047	0.331	0.235
	Model 3	Years climbing	-0.534	-2.345	-0.135	0.030	0.319	0.222
Treadwall $\dot{V}O_{2peak}$ (mL·kg·min^{-1})	Model 1:	Unadjusted	0.639	0.453	1.904	0.003	0.409	0.374
	Model 2:	Age	0.606	0.320	1.916	0.009	0.416	0.343
	Model 3:	Years climbing	0.597	0.329	1.872	0.008	0.428	0.357
Treadmill $\dot{V}O_{2max}$ (mL·kg·min^{-1})	Model 1:	Unadjusted	0.100	-0.605	0.888	0.692	0.010	-0.052
	Model 2:	Age	-0.022	-0.768	0.762	0.994	0.120	0.002
	Model 3:	Years climbing	0.085	-0.671	0.912	0.751	0.015	-0.116

β = beta, regression equation; Δ= delta score; TSI= tissue saturation index; O_2THR= time to half recovery of TSI% (oxidative capacity index); BF%= body fat percentage; LCI= lower confidence interval (95%); UCI= upper confidence interval (95%)

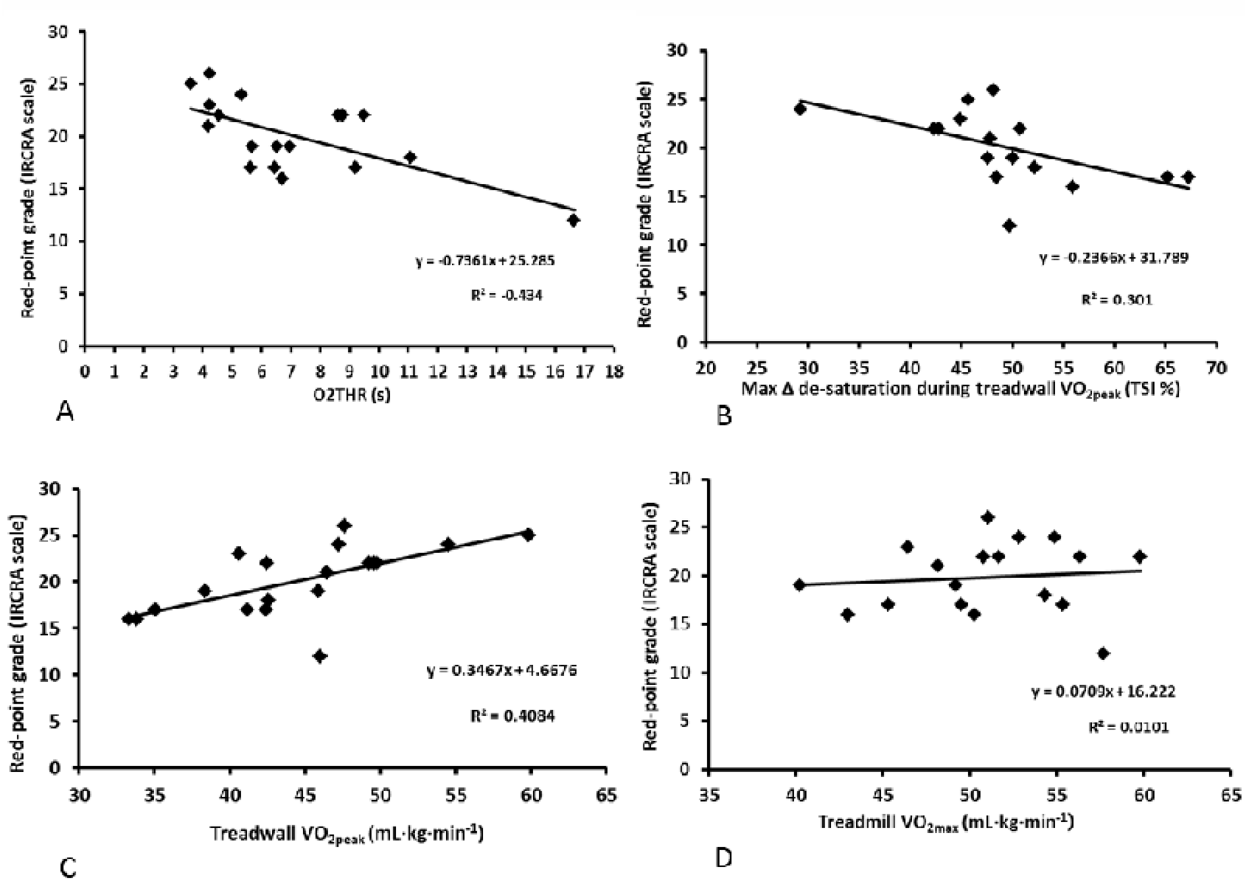

Figure 2 Linear regression models for O_2THR (oxidative capacity index) (A), maximal Δ de-oxygenation during treadwall $\dot{V}O_{2peak}$ test (TSI%) (B), treadwall $\dot{V}O_{2peak}$ (mL·kg·min^{-1}) (C), and treadmill $\dot{V}O_{2max}$ (mL·kg·min^{-1}) (D) and their relationship to the highest 6month self-reported red-point grade (International Rock Climbing Research Association grade scale).

Oxidative capacity index

Linear regression analysis (Table 2/Figure 2) revealed that oxidative capacity index of the FDP was inversely associated (β: -0.659 and 95% CI: -0.946 to -0.232; p= 0.003) with the highest self-reported red-point grade. After adjustment for age and climbing experience (years), a 1s decrease in O_2HTR (i.e. improvement in oxidative capacity index) was inversely associated (p= 0.003) with an increase of 0.750 (95% CI: 1.069 to 0.274) of a red-point grade (IRCRA). The percentage of variance (***R^2)*** explained was 44%.

Maximal de-saturation (Δ TSI%) during treadwall $\dot{V}O_{2max}$

Linear regression analysis (Table 2/Figure 2) revealed that the maximal de-saturation in the FDP achieved during the maximal treadwall test was significantly associated (p= 0.022) with the highest self-reported red-point grade. After adjustment for age and climbing experience (years), a 1% decrease in TSI was significantly associated (p= 0.047) with an increase of 0.498 (95% CI: 2.292 to 0.019) of a red-point grade (IRCRA). The percentage of variance (R^2) explained was 32%.

Treadwall $\dot{V}O_{2peak}$ (L·min^{1})

Linear regression analysis (Table 2/Figure 2) revealed that treadwall $\dot{V}O_{2peak}$ (mL·kg·min^{-1}) was significantly associated (p= 0.003) with the highest self-reported red-point grade. After adjustment for age and climbing experience (years), an increase of 1 mL·kg·min^{-1} was significantly associated (p= 0.009) with an increase of 0.606 (95% CI: 0.320 to 1.916) of a red-point grade (IRCRA). The percentage of variance (R^2) explained was 43%.

Treadmill $\dot{V}O_{2max}$ (L·min^{1})

Linear regression analysis (Table 2/Figure 2) revealed that before and after adjustment for age and climbing experience (years), treadmill $\dot{V}O_{2max}$ (mL·kg·min^{-1}) was not significantly associated (p = 0.692, 0.751 respectively) with the highest self-reported red-point grade (IRCRA).

Multiple regression

A multiple regression model using all significant aerobic predictors as independent variables (oxidative capacity index, Δ max de-oxygenation and treadwall $\dot{V}O_{2peak}$) was used to determine the combined contribution to red-point performance grade. As Durbin-Watson was 1.990 there were no meaningful serial correlations. After adjustment for age and climbing experience, the combined variables significantly (p= 0.001) explained 67.1% of the variance in self-reported red-point grade (R^2= 0.671, Adj R^2= 0.616).

DISCUSSION

Although previous cross sectional research has investigated cardiorespiratory and haemodynamic responses to sport climbing (10, 16, 18), to our knowledge this was the first study to assess the relationship between both haemodynamic and cardiorespiratory characteristics of rock climbers, and red-point sport climbing ability. Further, this is the first study to show that both climbing-specific assessments of maximal whole body aerobic capacity and a forearm specific aerobic capacity predict red-point sport climbing ability. Specifically, the main finding of the current study is that NIRS derived oxidative capacity index (O_2THR), maximal de-oxygenation during a maximal treadwall climbing test and treadwall $\dot{V}O_{2peak}$ similarly predict sport climbing performance and together explain 67% of the total variance. This is the first study to present data which suggests that rock climbing ability may in part be dependent on contributions from both forearm arm muscle aerobic capacity and whole body aerobic capacity, when determined using a sport specific ergometer (treadwall $\dot{V}O_{2peak}$ test). Dickson et al., (9) & Fryer et al., (18) found that $\dot{V}O_2$ consumption in elite and advanced sport climbers increased during a climb until the 3rd to 4th clip/bolt where a plateau occurred (route duration was 2-4 min). As such it was suggested that whole body aerobic metabolism may only be important for rock climbing performance up to a point, after which a forearm specific aerobic capacity may be more important. This contribution from the aerobic metabolism seems highly probably given that Table 2 and Figure 2 show that forearm oxidative capacity index, maximal de-oxygenation and treadwall $\dot{V}O_{2peak}$ all significantly predict climbing performance. Interestingly treadwall $\dot{V}O_{2peak}$ and forearm oxidative capacity index explained equal variance in performance (36%) suggesting that both the whole body $\dot{V}O_2$ and the aerobic capability of the forearms are equally important determinants of sport climbing performance. Additionally, when the aerobic predictors of performance are combined they explain 67% of the variance in red-point climbing performance.

During the maximal treadwall test, the greater level of de-oxygenation seen in higher level sport climbers was likely due to a number of physiological reasons. Firstly, maximal de-oxygenation obtained during sustained and intermittent finger flexion to failure has been shown to separate ability groups (21, 25, 28). Furthermore, it has been shown that elite climbers have a greater capillary filtration (32) and a higher vascular conductance (17) compared to non-climbers. As such it is possible that microvascular adaptations such as perfusion, muscle oxygen consumption and muscle blood flow within the flexor muscles may have contributed to the percentage of variance explained by the maximal forearm de-oxygenation (Table 2/Figure 2). However, it may be that these adaptations are particularly prominent in high level performers as Figure 2 (panels A and B) shows that such athletes (outliers) are likely to have affected the regression model. As such future research should look to consider whether these differences across ability levels are prerequisites to performance or if they are caused by central or localized mechanistic changes. However, determining the mechanisms behind this relationship is beyond the scope of this paper and further research is warranted.

As seen in Table 2, it is clear that forearm oxygenation kinetics and treadwall $\dot{V}O_{2peak}$ do not explain all variance in climbing performance. In addition to these measures it is important to consider that climbing performance is multifaceted. It is likely that both the oxidative capacity index, maximal de-oxygenation during a maximal treadwall test and $\dot{V}O_{2peak}$ do not explain all variance in sport climbing ability. Modern rock climbing, which is often performed on steep faces, is also likely to require a notable anaerobic contribution from the forearm flexors, particularly during the latter stages before exhaustion occurs (31), or during powerful moves used during the crux (most difficult) sections of a route. Furthermore, rock climbing performance encompasses psychological aspects such as perception affordance (7), and technical components such as footwork efficiency (4), handgrip strength (3), climber flexibility (8), and improved exercise economy (5). Although the current study provides important data to highlight the importance of a sport specific aerobic capacity and forearm oxidative capacity index, it should be noted that this study assessed the oxidative capacity index and maximal de-oxygenation which provides a complete representation of the capacity of the forearm to deliver and utilize oxygen within one flexor. Additionally, the self-report method used a 3:3:6 and not a 3:3:3 ratio as suggested by Draper (13).

However it was felt that as the climbers were from Southern Spain where the weather is favorable, a 6 months best grade may be more appropriate as it would reduce small variances in performance. Future studies should asses mitochondrial oxidative capacity (30), muscle oxygen consumption (30) muscle blood flow (33), forearm critical power (24) and a forearm specific aerobic/anaerobic ratio in-order to gain a better understating of the physiological mechanisms behind the increased oxidative capacity index, maximal de-oxygenation and increased treadwall $\dot{V}O_{2peak}$ seen in higher level sport climbers.

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PRACTICAL APPLICATIONS

Findings suggest that sport rock climbing performance is likely to be dependent on a notable contribution from 1) the local forearm aerobic capacity, and 2) whole body aerobic capacity when assessed using a sport-specific treadwall test, and not when assessed during traditional $\dot{V}O_{2max}$ treadmill exercise. As such coaches should consider using sport specific modalities for training which focus on both the forearm local muscle aerobic capacity as well as whole body aerobic capacity. Although there is potential for improving aerobic capacity using traditional modalities such as running, these may not be as effective as the previously mentioned sport specific training.

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