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TITLE
Differences in oxygenation kinetics between the dominant and non-dominant flexor digitorum profundus in rock climbers

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ABSTRACT

Purpose. This study examined differences in oxygenation kinetics in the non-dominant and dominant flexor digitorum profundus (FDP) of rock climbers. ***Methods.*** Participants consisted of 28 sport climbers with a range of on-sight abilities (6a+ to 8a French Sport). Using near infrared spectroscopy, oxygenation kinetics of the FDP was assessed by calculating the time to half recovery ($t_{½}$ recovery) of the tissue saturation index (TSI) following 3-5 min of ischemia. ***Results.*** A 2-way mixed model ANOVA found a non-significant interaction (p =0.112) for TSI x sex. However, there was a significant the main effect (p =0.027) handedness (dominant vs. non-dominant FDP). The dominant forearm recovered 13.6% quicker ($t_{½}$ recovery mean difference = 1.12 sec, 95% CI 0.13 to 2.10 sec) compared to the non-dominant FDP. This was not affected by 6-month on-sight climbing ability or sex (p =0.839, p =0.683). ***Conclusions.*** Significant intra-individual differences in oxygenation kinetics of the FDP were found. Improvements in oxygenation kinetics within the FDP are likely due to the abilities of the muscle to deliver, perfuse and consume oxygen. These enhancements may be due to structural adaptations in the microvasculature such as an increase in capillary density and an enhanced improvement in capillary filtration.

KEY WORDS

Rock Climbing, Asymmetry, Handedness, Oxygenation kinetics, Near Infrared Spectroscopy

INTRODUCTION

Rock climbing requires repeated isometric contractions of the finger flexors, especially the flexor digitorum profundus (FDP), which is responsible for flexion of the metacarpophalangeal and interphalangeal joints, used in the open crimp position[1]. These contractions cause regular periods of ischemia within the forearms; the extent of this ischemia and the subsequent recovery from this has been shown to differentiate ability groups of rock climbers[2]. As such, fatigue resistance of the finger flexors is considered one of the most significant determining factors in climbing performance[3]. Recent research suggests that utilisation of oxygen in the FDP, rather than the ability to deliver oxygen to the limb (brachial artery blood flow) is more important for determining performance[4].

Asymmetry in the load application time between the dominant and non-dominant hand has been demonstrated in rock climbers[5]. This irregularity resulted in the dominant hand receiving less relief time and longer periods of work time. Currently, it is unknown whether this irregularity affects the ability of the forearm to deliver, perfuse and consume oxygen at a muscular level. Therefore, this study aimed to assess oxygenation kinetics, which represents perfusion, oxygen delivery and consumption in the non-dominant and dominant FDP in sport rock climbers.

METHOD

Participants. Twenty-eight rock climbers (10 female and 18 male) completed the study (age 34.9 ± 6.0 years; height 1.7 ± 0.1 meters; mass 63.8 ± 8.6 Kg). The climbers were classified as intermediate through to elite[6] ranging in self-reported on-sight ability in the past six months from French 6a+ to 8a (UIAA VII- to X-). Non-smoking volunteers who were not on any vascular-acting medication were selected for participation based on having no known cardiovascular or respiratory diseases. Written informed consent and medical health questionnaires were completed prior to taking part in the study. Institutional ethical approval was granted prior to data collection and conformed to the principles of the declaration of Helsinki.

Procedure. Participants were asked to refrain from caffeine and strenuous exercise for 24 hours prior to testing. Each participant completed all testing during a single visit to an environmentally controlled exercise physiology laboratory. Participants were asked to lie in a supine position for 15 min of quiet rest. Near infrared spectroscopy (NIRS) was used to assess skeletal tissue oxygenation responses during a 3 to 5 min occlusion at 220 mmHg (Hokanson rapid inflation cuff) in both the dominant and non-dominant FDP. A period of 30 minutes separated each occlusion.

Near Infrared Spectroscopy. The portable NIRS apparatus (Portalite, Artinis, Medical System, Zetten, The Netherlands) used in this study is a 2-wavelength continuous wave system sampling at 25Hz. Optodes were held in place over the FDP with medical tape and loosely covered with a crepe bandage to ensure there was no ambient light interference. To locate the FDP each participant performed a contraction by opposing the fingers and thumb, the flexor was palpated to locate the middle of the muscle[7]. As the forearm is not a major site of fat storage and climbers are characterised by their low body fat percentage the effect of adipose tissue on the NIRS signal was considered negligible.

Muscle oxygenation measures. In this study oxygenation kinetics is discussed with respect to the time to half recovery ($T_{½}$ recovery) of the tissue saturation index (TSI). TSI is determined by $O_2Hb/(O_2Hb+HHb)$ and is presented as a percentage and as such it is considered to be a reflection of muscle perfusion, oxygen delivery and oxygen consumption[8]. Assessments of TSI have been used to separate ability groups in rock climbing during sustained[4] and intermittent[2] contractions as well as during recovery post exhaustive handgrip exercise[9].

In the current study participants briefly performed light handgrip exercise for 10 sec, at approximately 10% of their maximum voluntary contraction to activate their aerobic metabolism. Immediately following exercise the tourniquet (Hokanson Inc, WA, USA) was rapidly inflated to 220mmHg. Values of TSI were visually monitored, when they stabilised for 30s at their lowest point (somewhere between 3 and 5 min) the tourniquet was rapidly released. Time to half recovery was determined as half of the time difference between the lowest point of de-oxygenation and the highest point of re-oxygenation (hyperaemic phase post cuff release).

Statistical Analysis. All analyses were performed using Statistical Package for Social Sciences (SPSS; Version 22) and Microsoft Excel (2016). For all analyses, the critical α-level was set at 0.05. Using the Kolmogorov-Smirnov goodness-of-fit test and Levene's test, all data were found to be normally distributed with equal variance. To determine the difference in $t_{½}$ recovery between the dominant and non-dominant FDP, a 2-way mixed model ANOVA was used. Because a non-significant interaction was found for mean $t_{½}$ recovery x sex, all the analyses were conducted for male and female together, sex was included as covariate.

RESULTS

There was a non-significant interaction for mean TSI $t_{½}$ recovery x sex (P =0.112, eta^2=0.142). However, there was a significant main effect for handedness (P =0.027, eta^2=0.255) with the dominant FDP recovering quicker than the non-dominant (mean difference = 1.12 sec, 95% CI 0.13 to 2.10 sec). The dominant flexor was 13.6% quicker compared to the non-dominant as presented in Fig. I. The covariates on-sight ability and sex did not significantly affect the model (p =0.839, p=0.683 respectively).

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DISCUSSION

The main finding of this study was that the oxygenation kinetics in the FDP of sport rock climbers is significantly quicker in the dominant FDP compared to the non-dominant and this was not affected by sex or climbing ability. As such, this is the first study to show that oxygenation kinetics, which includes perfusion, oxygen delivery and consumption in the forearm flexors of rock climbers, may be a trainable aspect of performance and not a pre-requisite. Although previous research[4] has suggested that there are no differences in macro-vascular structure between ability groups (brachial artery diameter and blood velocity), microvascular adaptions have been suggested as climbers have been shown to be able to de-oxygenate the FDP more[2, 4, 9], and recover faster post-exercise[9] than lower grade climbers. In agreement with previous research by España-Romero and Watts[10], we feel that more advanced sport climbers may have an increased capillary density. However, we now know that even in these more advanced climbers, there remain differences in oxygenation kinetics between the dominant and non-dominant forearm muscles, and this is likely to affect overall climbing performance.

During high-intensity isometric contractions, as seen in rock climbing, local blood flow is compromised for short amounts of time[11], which in turn increases the build-up of metabolic waste products. However, increased oxidative capacity, oxygen delivery and oxygen consumption are coupled with a greater ability to deal with the metabolic waste associated with forearm ischemia. Importantly, findings from the current study suggest these differences occur intra-individually, likely resulting in an asymmetry in the performance of the dominant and non-dominant FDP. As such determining optimal training methods for the FDP may improve

both metabolic clearance and endurance performance (a major determinant of sport rock climbing performance[12]).

Uneven load application time between the dominant and non-dominant hand has been demonstrated in climbers, with the dominant hand receiving less relief time and longer proportions of work-time[5]. It is possible to speculate that the handedness observed by Donath et al.[5] is a compensatory mechanism for poor metabolic performance in the non-dominant arm. This is further supported by an increased reliance on the dominant arm when fatigued, shown by a decrease in the work to relief ratio[5]. It is highly probable that the differences between flexors in both Donath et al.[5] research and the present study are linked to excessive reliance on the dominant hand leading to training adaptations. Future studies should look to implement climbing specific training programmes that focus on forearm strength and endurance performance to provide clarity on this speculation, and ultimately highlight the most effective methods for trainers/coaches.

The current study provides new insight regarding the importance of forearm oxygenation kinetics and has made several advancements on previous research: 1) irrespective of sex or climbing ability, sport rock climbers have faster oxygenation kinetics in the dominant FDP compared to the non-dominant; and 2) unlike previous studies which had potential error in the data as maximal exercise and metabolic acidosis may effect the NIRS signal[13], this study used a torniquet to maximally de-oxygenate the muscle. However, it should be acknowledged that this study assessed the TSI response, which provides a complete representation of the capacity to deliver, perfuse and utilise oxygen within one flexor muscle and may not be representative of the whole forearm. Future studies should i) assess oxidative capacity within a variety of flexors to determine the most important flexor for performance, and ii) assess mitochondrial oxidative capacity, muscle blood flow and muscle oxygen consumption in said flexors.

PRACTICAL APPLICATIONS

The findings of this study have implications for rock climbing athletes, coaches and researchers looking to understand and improve upon the performance of the forearms flexors. The present study is the first to demonstrate that oxygenation kinetics in the forearm flexors of sport rock climbers is faster in the dominant side independent of gender, and that response is not affected by self-reported on-sight climbing ability. Whilst further research is still necessary, the short-term advice is that climbing coaches should consider unilateral forearm training to ensure parity between dominant and non-dominant forearm flexors in all climbers regardless of gender or on-sight ability.

CONCLUSION

Oxygenation kinetics in the FDP of rock climbers is significantly greater in the dominant hand compared to the non-dominant. Therefore, the major finding of this study is that there is significant intra-individual differences in the ability to deliver, perfuse and use oxygen within the FDP. Enhancements in oxygenation kinetics may be due to structural changes in the microvasculature such as an increase in capillary density and enhanced capillary filtration.

CONFLICT OF INTEREST

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

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FIGURES

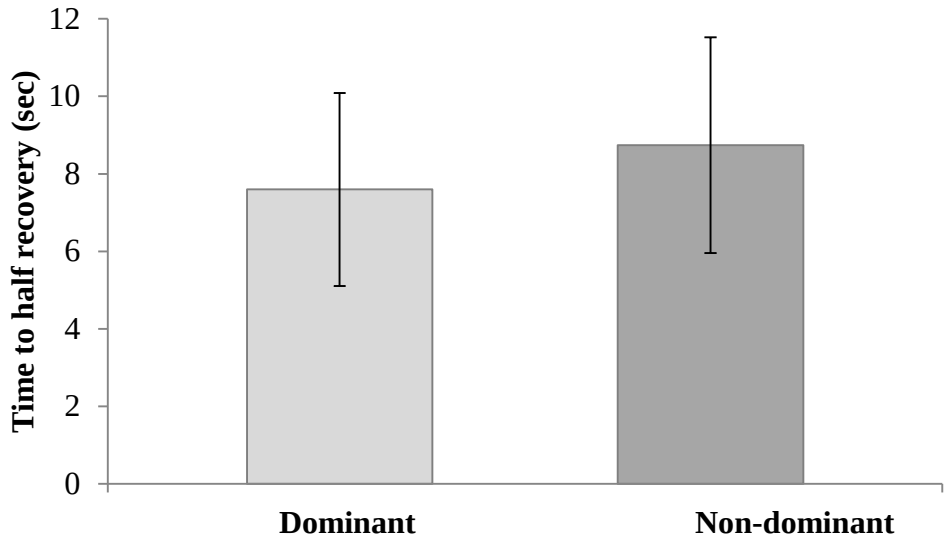

Fig. I Time to half recovery (sec) of tissue saturation index, as determined by near infrared spectroscopy, in the flexor digitorum profundus (FDP) of the dominant and non-dominant arms of 28 rock-climbers. Results expressed as mean ± SD.