ACTA UNIVERSITATIS CAROLINAE
KINANTHROPOLOGICA Vol. 51, 2 – 2015 Pag. 48–55

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FOREARM MUSCLE OXYGENATION DURING SUSTAINED ISOMETRIC CONTRACTIONS IN ROCK CLIMBERS

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ABSTRACT

Background. Bouldering and lead climbing are divergent disciplines of the sport of rock climbing. Bouldering moves are short and powerful, whilst sport climbing is longer and require a greater degree of endurance.

Aim. The aim of this study was to compare forearm muscle oxygenation during sustained isometric contraction between lead climbers (LC) and boulderers (BO).

Methods. Eight BO and twelve LC completed maximal finger flexor strength test and sustained contractions to exhaustion at 60% of maximum voluntary contraction (MVC).

Differences between BO and LC in maximal strength, time to exhaustion, force time integral (FTI), and tissue oxygenation (SmO_2) were assessed by t-test for independent samples.

Results. LC showed significantly lower level of average tissue oxygenation (BO 38.9% SmO_2, $s = 7.4$; LC 28.7% SmO_2, $s = 7.1$) and maximal tissue deoxygenation (BO 25.6% SmO_2, $s = 8.2$; LC 13.5% SmO_2, $s = 8.5$). LC demonstrated significantly lower finger flexor strength (519 N, $s = 72$) than BO (621 N, $s = 142$). LC sustained a longer time of contraction (not significantly) (BO 52.2 s, $s = 11.5$; LC 60.6 s, $s = 13$) and achieved a similar value of FTI (BO 17421 Ns, $s = 4291$; LO 17476 Ns, $s = 5036$) in the endurance test.

Conclusions. The results showed lower deoxygenation during sustained contraction in BO than LC despite similar FTI, indicating different local metabolic pathways in both groups.

Keywords: muscle oxygenation; isometric contraction; continuous test; sport climbing; bouldering; lead climbing

DOI: 10.14712/23366052.2015.31

INTRODUCTION

Bouldering and lead climbing are divergent disciplines of the sport of rock climbing. Whilst both require participants to ascend routes, and are practiced indoors and outdoors, and both have increased in popularity as competitive and non-competitive activities during the last 20 years, there are several notable differences (discussed later in the text)

(Fanchini, Violette, Impellizzeri & Maffiuletti, 2013; Mermier, Robergs, McMinn & Heyward, 1997; Sheel, 2004). Bouldering is performed low to the ground, and movements are very gymnastic and powerful; problems are generally up to 4 meters high, and take around 30 seconds (Macdonald & Callender, 2011; White & Olsen, 2010). Conversely, lead climbing requires greater endurance, participants ascend longer routes that are generally around 15 meters, and take 2 to 7 minutes to complete (Watts, 2004). Climbing-related research in physiology has focused mainly on lead climbers (e.g. Grant, Hynes, Whittaker & Aitchison, 1996; Sheel, 2004; Watts, 2004). Very few studies have analysed the specificity of bouldering and lead climbing (e.g. Fanchini et al., 2013; Macdonald & Callender, 2011; Michailov, Mladenov & Schöffl, 2009; White & Olsen, 2010).

Climbing requires repeated isometric contractions of the finger flexors. Finger flexor endurance has been found to be closely related to lead climbing performance (Baláš, Pecha, Martin & Cochrane, 2012); whilst boulderers have been found to have greater relative finger flexor strength and rates of force development than lead climbers (Fanchini et al., 2013; Michailov et al., 2009). It is assumed that different forearm muscle adaptations are related to bouldering and lead climbing training.

Recently, the local oxidative capacity of the finger flexors has been assessed using near infrared spectroscopy (NIRS) (Fryer, Stoner, Lucero et al., 2015; Fryer, Stoner, Scarrott et al., 2015; MacLeod et al., 2007; Philippe, Wegst, Muller, Raschner & Burtscher, 2012). Greater climbing ability has been related to a greater degree of reoxygenation during intermittent handgrip contraction (Fryer, Stoner, Scarrott et al., 2015). The degree of reoxygenation was in close relationship with the test performance ($R^2 = 0.41$) (MacLeod et al., 2007). During sustained handgrip contractions, lower grade climbers showed very low ability for tissue deoxygenation, while elite climbers achived a very low level of tissue oxygen saturation (SMO_2) at the end of contraction (Fryer, Stoner, Scarrott et al., 2015). As only lead climbers were assessed, these localised adaptations are only speculative in boulderers. As such, the aim of this study was to compare changes in the oxygenation of the finger flexor muscle, during an isometric contraction, between lead climbers and boulderers.

METHODS

Participants. Twenty climbers participated (28.3 yrs, s = 6.7; 71.2 kg, s = 8.6; 177.5 cm, s = 6.5). Climbers were recruited from local climbing clubs and were classified as advanced, based upon their self-reported red-point (RP) grade (Draper et al., 2015). Participants were divided into two groups according to their climbing discipline preferences (LC = 12; BO = 8) (Table 1). Informed consent was obtained from the participants, after a detailed description of the measurements was provided. Approval was granted by University Ethical Committee.

Study design. A single factor approach was selected in order to asses the differences between BO and LC. Participants first completed questionnaires concerning their ability level and climbing experience. Anthropometric measurements (body mass, height) and a standardised warm-up were then completed. The warm-up consisted of 5 mins of stair-walking, 5 mins traversing on the climbing wall and 5 mins individual intermittent hanging on a 23–30 mm deep wooden rung. After the warm-up, each participant performed the maximal finger strength test. Following 10 mins of passive rest, participants then performed the sustained finger flexors contraction until exhaustion.

Strength measurement. A finger strength measurement device was used to assess the climbers' maximum finger strength and endurance (3D-SAC; National Sport Academy in Sofia in Bulgary; Fig. 1). The 3D-SAC was configured with a 23 mm deep wooden hold with a radius of 12 mm (Amca, Vigouroux, Aritan & Berton, 2012; Baláš, Mrskoč, Panáčková & Draper, 2015), attached to a 3D force sensor (measuring range ± 2 kN, comprehensive accuracy 0.5%, sample rate 125 Hz). The intensity and duration of the effort and the rest intervals during each repetition were programmed into the device. Participants were provided with visual and acoustic signals whilst performing the test.

In order to maximise potential finger flexor activation the participant's arm was placed with 180° shoulder flexion and full elbow extension (Baláš, Panáčková, Kodejška, Cochrane & Martin, 2014). All measurements were undertaken in a seated position, with the shoulder of the tested arm placed vertically under the wooden hold (Fig. 1). If a climber was able to hold himself on one arm, a weight-vest of 10 kg was provided. Participants dried their hands using climbers' chalk (magnesium carbonate) before testing. The wooden hold was regularly brushed to provide the same friction conditions for all participants.

Maximal strength testing (MVC) was completed twice, separated by 2 mins rest. On presentation of an acoustic signal, climbers were asked to pull progressively on the hold, to load their maximal weight on to the tested arm for a period of 5 secs. They were verbally encouraged to achieve maximal effort. The highest value from the two trials was taken as their MVC for the following endurance tests. The endurance strength test was undertaken in the same position at 60% of MVC. As before, the test started on an acoustic signal, and the climbers had visual feedback to maintain the correct level of applied force. If the level of applied force dropped under 10% of target performance for more than one second, the test was automatically halted. For the purposes of statistical analysis, time within the target limits was taken as time of the test. Force time intergral (FTI) was calculated as average force applied on the hold in the target zone multiplied by total actual contraction time.

Figure 1. Special dynamometry – 3D-SAC for measurement finger flexor strength, body and finger position during the tests

Muscle tissue oxygenation. The flexor digitorum profundus (FDP) was monitored for the level of muscle tissue oxygenation during the contraction and recovery periods. FDP is the dominant flexor muscle used during open grip positions (Schweizer & Hudek, 2011) and is easily palpable at one third of the line between the medial epicondyle and the styloid process of the ulna (Fryer, Stoner, Scarrott et al., 2015). Near infrared spectroscopy (Moxy, Minnesota, USA) was used to assess muscle tissue oxygenation. Moxy measures the ratio of the oxyhemoglobin concentration to the total hemoglobin concentration in the muscle in real time and reports it as a percentage, which is indicated as muscle oxygen saturation or muscle oxygenation (SmO_2) (Ferrari, Mottola & Quaresima, 2004; Quaresima, Lepanto & Ferrari, 2003). Data was stored and extracted from the internal memory of the device as a .csv file. An extraction programme written in R used the data points to plot the time constant upon which the oxygenation was determined.

Data analysis. All the variables met the assumption for normal distribution using Kolmogorov-Smirnov's test. Descriptive statistics (mean, *s*) were used to characterise the level of strength, endurance and muscle oxygenation for all participants and ability subgroups. To assess statistical differences between LC and BO, t-test for independent samples was calculated. Statistical significance was set to $P < 0.05$. Cohen d was computed to estimate the effect size. The effect was interpreted as follows: 0.41 minimum practical effect, 1.15 moderate effect and 2.70 strong effect (Ferguson, 2009). The relationship between climbing specific strength to RP performance ability was assessed by Pearson correlation coefficient. All calculations were completed in Microsoft Excel and IBM SPPS for Windows (Version, 22, Chicago, Il., USA).

RESULTS

Performance and anthropometric characteristics are shown in Table 1. LC have similar climbing ability RP in leading as BO. However BO performed higher in bouldering.

Table 1. Anthropometric and performance characteristic RP (red point) in boulderers and lead climbers. Data are represented as mean ± standard deviation.

Participants	Age (years)	Body mass (kg)	Height (cm)	RP leading IRCRA	RP boulder IRCRA
Boulderers (N = 8)	25.7 ± 7.9	71.5 ± 10.3	180.6 ± 6.4	18.1 ± 4.6	20.6 ± 5.6
Lead climbers (N = 12)	30.0 ± 5.6	71.1 ± 7.8	175.4 ± 5.9	17.8 ± 5.1	19.9 ± 4.7
Total (N = 20)	28.3 ± 6.7	71.2 ± 8.6	177.5 ± 6.5	17.9 ± 4.8	20.2 ± 4.9

BO performed significantly better in maximal finger strength than LC (Table 2). BO had on average by 102 N higher absolute strength and by 1.45 $N.kg^{-1}$ higher strength normalized to body mass than LC. LC sustained for longer (although not significantly) by 8.4 s than BO in the endurance test. FTI in LC was also similar to BO despite higher maximal strength of BO (Table 2). Significant differences were found between BO and LC in maximal deoxygenation and in average oxygenation. BO demonstrated a lower level of maximal deoxygenation (12.1% SmO_2) than LC. Average SmO_2 in BO was by 10.2% higher than in LC, indicating a lower use of oxygen in BO during sustained contraction (Table 2).

Table 2.

Maximal strength test	Boulderers (N = 8)	Lead climbers (N = 12)	P	Cohen *d*
Finger strength (N)	621 ± 142	519 ± 72	0.046	0.97
Finger strength ($N.kg^{-1}$)	8.82 ± 2.25	7.35 ± 1,18	0.072	0.87
Endurance test				
Deoxygenation max (% SmO_2)	25.6 ± 8.2	13.5 ± 8.5	0.005	1.46
Oxygenation avg (% SmO_2)	38.9 ± 7.4	28.7 ± 7.1	0.006	1.41
Test time (s)	52.2 ± 11.5	60.6 ± 13.0	0.152	0.68
FTI (N.s)	17421 ± 4291	17476 ± 5036	0.980	0.01
FTI ($N.s.kg^{-1}$)	250 ± 80	249 ± 74	0.977	0.01

Deoxygenation max – the highest deoxygenation; Oxygenation avg – average oxygenation during the test; Test time – time of contact between the fingers and hold at 60% ± 10% MVC; FTI – Force time integral.

Figure 2 shows the typical decline of muscle tissue oxygenation during sustained contraction in BO and LC. Typically, differences between LC and BO are evident after ~10 s of isometric contraction. A significant correlation was found between the RP performance of lead climbing and maximal ($R^2 = 0.37$) relative strength ($R^2 = 0.49$), FTI ($R^2 = 0.36$) and FTI related to body mass ($R^2 = 0.44$).

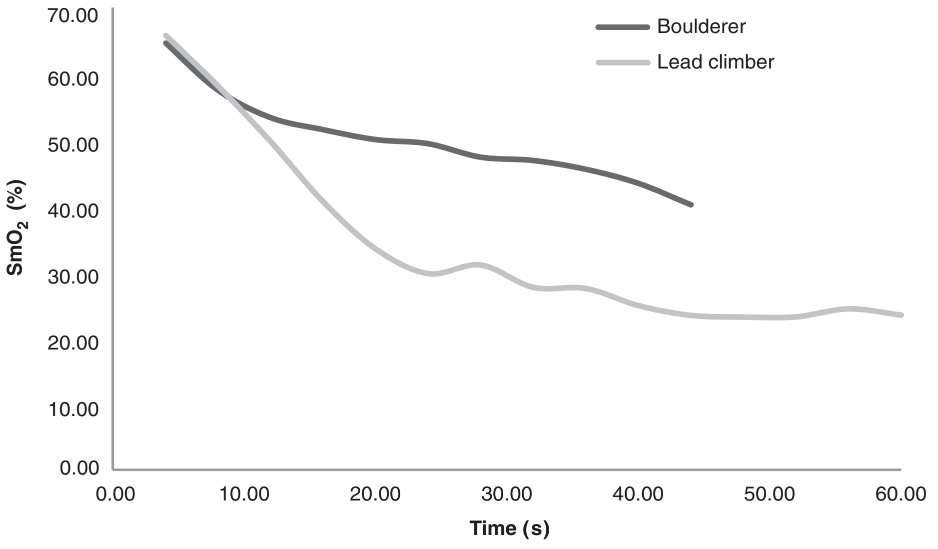

Figure 2. Muscle tissue oxygenation of flexor digitorum profundus during sustained contraction; BO – typical boulderer, LC – typical lead climber

DISCUSSION

The main aim of the study was to compare changes in the oxygenation of the finger flexor muscle, during an isometric contraction, between LC and BO. LC were able to deoxygenate the FDP to a greater extent than BO during sustained contraction, and this difference occured despite similar ability and performance characteristics (time to exhaustion, FTI). According to these results, it is suggested that these differences are due to climbing discpline-specific finger flexor adaptations. Previous research (Fryer, Stoner, Scarrott et al., 2015) has suggested that there are no differences in the macrovascular structure of the finger flexors between ability groups, although microvascular adaptions have been reported (Thompson, Farrow, Hunt, Lewis & Ferguson, 2014). Moreover, experienced climbers have been shown to be able to deoxygenate the FDP to a greater extent than their lower grade counterparts (Fryer et al., 2014; Fryer, Stoner, Scarrott et al., 2015; Fryer et al., 2015). In addition to ability-differentiated differences in the microvascular structure of the forearms of climbers seen previously, the present study shows that there are discipline-specific adaptations. Further, this also suggests that these metabolic and structural adaptations are trainable characteristics.

Adaptations to the finger flexors of LC and BO occur in order to meet the differing metabolic demands of the two disciplines. Leading a route generally lasts for 2–7 minutes, where contact time with the hold is around 10 s and time to relief ratio varies from 3 : 1 to 7 : 1 (Michailov, 2014; Watts, 2004). Whilst time of boulder ascent lasts for ~30 s, contact time between the fingers and holds is ~8 s and time to achieve the next hold is ~0,6 s (White & Olsen, 2010). From the time motion description, it is speculated that LC places greater demands on aerobic metabolic pathways. Conversely, bouldering encompasses very short relief phases during the hand transfer, and so limited vascular vasodilatation and low blood flow may occur. Therefore, greater demands on local anaerobic pathways are to be expected. The results of the current study are in agreement with this suggestion, as BO demonstrated a lower local capacity to use oxygen during sustained contraction than lead climbers.

Several authors have observed a greater degree of deoxygenation and reoxygenation of forearm muscles during intermittent handgrip contraction with increasing climbing ability (Fryer, Stoner, Lucero et al., 2015; MacLeod et al., 2007; Philippe et al., 2012). The reoxygenation occurred during a 2 s phase of the relief phase of the intermittent contraction and was attributed to higher adaptive vascular capacity of lead climbers, such as capillary density and O_2 permeability (Fryer, Stoner, Lucero et al., 2015). During sustained contraction, Fryer et al. (2015) found significance differences between climbing ability groups in oxygenation drop in lead climbers (non-climbers 32%, intermediate 34.3%, advanced 42.8%, elite 63.1%), although all groups did very similar work (FTI). The authors attribute the results to vascular adaptation on training and point out the higher use of oxygen in the forearm muscle even under high vascular occlusion.

There were no differences in time to exhaustion between BO and LC. This finding is in agreement with other authors, who confirmed that the time of sustained contraction at the same intensity of MVC is not a suitable indicator to assess local endurance in climbers (Ferguson & Brown, 1997; Fryer, Stoner, Scarrott et al., 2015; MacLeod et al., 2007). The time to exhaustion in the current study was substantially lower than in other studies (92.6-1412 s) because of the higher intensity (60% MVC) than previously used (40% MVC) (Fryer, Stoner, Scarrott et al., 2015; MacLeod et al., 2007; Philippe et al., 2012). In the current study, BO demonstrated similar FTI as LC during the sustained contraction. FTI is a very useful indicator of endurance performance in the intermittent contraction as it differentiates very well between climbing ability groups (MacLeod et al., 2007; Philippe et al., 2012). However, its use in sustained contraction testing to differentiate climbing ability is speculative (Fryer, Stoner, Scarrott et al., 2015) and it is unsuitable in differentiating BO from LC.

The present study provides a new understanding regarding discipline-specific adaptations within the finger flexors of BO and LC. However, there are at least two limitations of the study: 1) climbers self-selected into the BO or LC groups according their preferences; 2) climbers were of varying climbing abilities, and it is acknowledged that climbing difficulty level and other factors such as gender, general fitness, motivation and training status may also influence muscle oxygenation. Future studies should evaluate local adaptations after specific training programmes to understand specific local adaptations on intermittent and sustained contractions. The authors acknowledge that the results cannot be generalised, as the sample size in both groups was limited and covered a wide range of ability level.

CONCLUSION

To conclude, the main finding of this study was that LC were able to deoxygenate the FDP to a greater extent than BO during a sustained contraction at 60% of MVC, and this difference occured despite similar time to exhaustion and FTI. This represents a discipline-specific adaptation to the FDP, associated with lower local aerobic capacity in BO, and conversely greater capacity in LC. Moreover, BO demonstrated higher climbing specific maximal strength than LC. Coaches and climbers might therefore use bouldering and lead climbing for specific metabolic adaptations of forearm muscles.

ACKNOWLEDGEMENTS

This study was written within the Programme for the Development of Fields of Study at Charles University, No. P38 Biological aspects of the investigation of human movement. The authors have no conflict of interest in connection with this paper. The authors thank David Giles and Simon Fryer for their special comments and English correction, and National Sports Academy for a support.

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