

## FOREARM ISOMETRIC FATIGUE-RESISTANCE IN CLIMBERS IS SUPERIOR TO RESISTANCE TRAINED ATHLETES AND AEROBICALLY TRAINED CONTROLS WHEN MATCHED FOR GRIP STRENGTH.

Peoples, G. E.<sup>(1)</sup>, Nolan, J.<sup>(2)</sup> and McLennan, P. L.<sup>(3)</sup>

<sup>(1)</sup>School of Medicine, University of Wollongong, Australia. peoples@uow.edu.au

<sup>(2)</sup>School of Medicine, University of Wollongong, Australia. jtn193@uowmail.edu.au

<sup>(3)</sup>School of Medicine, University of Wollongong, Australia. petermcl@uow.edu.au

**Introduction:** This study compared the forearm isometric fatigue of rock climbers (RC) to strength-matched resistance trained (RT) and aerobically trained (AT) athletes. **Methods:** AT (n=6, 23±1y, 77±1kg), RT (n=7, 24±1y, 80±3kg) and RC (n=8, 25±2y, 74±2kg) completed three forearm fatigue protocols (sustained MVC, sustained 40% MVC [3mins], intermittent 40% MVC [5s contraction, 5s recovery, 3mins]) and a controlled forearm occlusion (5min) assessment. Physiological measurements included grip force, EMG and NIRS. **Results:** Forearm flexor thickness and MVC were equivalent between groups ( $P>0.05$ ). Sustained MVC force (time to decline 50% MVC) was longer in the RC versus AT (AT: 35±5, RT: 46±6, RC: 54±4s,  $P<0.05$ ) and both RT and AT for sustained 40% MVC (AT: 56±9, RT: 62±8, RC: 87±7s,  $P<0.05$ ). Reduction in MVC was less in RC post intermittent 40% contractions ( $P<0.05$ ). Oxygen desaturation half-time was longer in the RC versus AT (AT: 65±9, RT: 86±7, RC: 99±7s,  $P<0.05$ ) and this was associated with time to 50% MVC ( $P<0.05$ ,  $r^2=0.53$ ) and time to 40% MVC task failure ( $P<0.05$ ,  $r^2=0.30$ ). **Discussion:** RC had superior isometric fatigue-resistance compared to RT and AT athletes matched for MVC and muscle thickness. An improved oxygen cost during controlled ischemia partly explained these adaptive responses to training.

**Key words:** occlusion; muscle tissue oxygen saturation; NIRS

**Introduction:** Cette étude a comparé la fatigue isométrique de l'avant-bras des grimpeurs (RC) à des athlètes de résistance assortis (RT) et aérobiques (AT). **Méthodes:** AT (n = 6, 23 ± 1y, 77 ± 1kg), RT (n = 7, 24 ± 1y, 80 ± 3kg) et RC (n = 8, 25 ± 2y, 74 ± 2kg) ont terminé trois fatigue de l'avant-bras protocoles (MVC soutenue, 40% MVC soutenue [3mins], MVC intermittent 40% [contraction 5s, récupération 5s, 3mins]) et une évaluation contrôlée de l'occlusion de l'avant-bras (5min). Mesures physiologiques, y compris la force de préhension, EMG et NIRS. **Résultats:** L'épaisseur du fléchisseur de l'avant-bras et le MVC ont été appariés entre les groupes ( $P > 0,05$ ). La force MVC soutenue (temps à 50% MVC) était plus longue dans le RC versus AT (AT: 35 ± 5, RT: 46 ± 6, RC: 54 ± 4s,  $P < 0,05$ ) et à la fois RT et AT pour 40% (AT: 56 ± 9, RT: 62 ± 8, RC: 87 ± 7s,  $P < 0,05$ ). Réduction de MVC était moins dans RC post intermittent 40% contractions ( $P < 0,05$ ). La demi-période de désaturation de l'oxygène était plus longue dans le RC versus AT (AT: 65 ± 9, RT: 86 ± 7, RC: 99 ± 7s,  $P < 0,05$ ) et ceci était associé avec le temps jusqu'à 50% MVC ( $P < 0,05$ ,  $r^2 = 0,53$ ) et l'échec de la tâche MVC à 40% ( $P < 0,05$ ,  $r^2 = 0,30$ ). **Discussion:** RC présentait une résistance à la fatigue isométrique supérieure à celle des athlètes RT et AT correspondant à MVC et à l'épaisseur des muscles. Un coût en oxygène amélioré pendant l'ischémie contrôlée explique en partie ces réponses adaptatives à l'entraînement.

**Mots-clés:** occlusion; la saturation en oxygène du tissu musculaire; NIRS

**Introduction:** Rock climbing performance is associated with fatigue resistance of the forearm muscles groups, associated with improved muscle tissues oxygen status (Fryer *et al.*, 2016). Increased muscle oxygen capacity (Fryer *et al.*, 2017) and faster re-oxygenation (Philippe *et al.*, 2012) are proposed mechanisms that may partly contribute to such fatigue resistance. Nonetheless, comparisons between individuals with varying climbing performance, or controls, often do not account for skeletal muscle cross sectional area and strength. This is important, as independent variables may influence the overall interpretation of the contractile fatigue (Grassi *et al.*, 2015). Notably, from a first principles perspective in muscle function, forearm fatigue in rock climbers has never been compared to other athletes, such as strength-matched resistance trained individuals. This latter group is an interesting model, as they also rely on forearm muscle contractile force (gripping), however, only for a very brief period of time. Therefore, this study compared the forearm isometric fatigue of rock climbers (RC) to both strength-matched aerobically trained (AT) (no forearm gripping experience) and resistance trained (RT) athletes (maximal gripping experience) with the hypothesis that oxygen status would predict fatigue resistance, accounting for grip strength and muscle cross sectional area.

**Methods:** Aerobically trained (AT) (n=6, 23±1 y, 77±1kg), resistance trained (RT) (n=7, 24±1y, 80±3kg) and rock climbers (RC) (n=8, 25±2y, 74±2kg) were carefully selected for grip strength by assessing maximal voluntary contraction (MVC). Additionally, the groups were matched for forearm flexor muscles thickness (including flexor digitorum superficialis [FDS] and flexor digitorum profundus [FDP]), as a surrogate of cross sectional area, using ultrasound technology (Vivid iq, GE, Australia). These two steps were important so as to account for independent variables that confound interpretation of contractile fatigue between groups.

Subjects completed three forearm isometric grip fatigue protocols (1. sustained MVC [100%], 2. sustained 40% MVC [3mins], 3. intermittent 40% MVC [5s contraction, 5s recovery, 3mins]) on separate occasions. The intermittent 40% MVC also involved a 100% MVC (5s) before (unfatigued) and 30 seconds after the completion of the 3 minutes (fatigued). Physiological measurements included grip force (N), muscle activation (EMG, mV), and heart rate (bpm) using continuously recorded Labchart (ADInstruments, Australia) and muscle tissue oxygen saturation using NIRS (Moxy, MN, USA). The NIRS monitor was located on the skin, using ultrasound imaging, directly above the centre of the flexor muscle group including FDS and FDS. In addition, also on a separate occasion, all subjects completed a controlled forearm occlusion (5mins) assessment (cuff pressure +60 mmHg >SBP) to determine half-time desaturation (resting conditions). The rapid inflation cuff (Hakenson, WA, USA) was placed on the brachium, rapidly inflated (3 seconds) and the pressure maintained for a total duration of 5 minutes, and then finally rapidly deflated (3 seconds). Physiological measurements including heart rate (bpm) and muscle tissue oxygen saturation using NIRS were continuously recorded. Once again, the NIRS monitor was located on the skin, using ultrasound imaging, above the centre of FDS and FDS.

Data was analysed using Statistix, v10 (USA). One-way ANOVA, with Bonferroni post-hoc analysis was used to determine where group means were significantly different. Pearson's correlations were used to determine associations. Alpha was set at  $P<0.05$ . Demographic data expressed mean (SD) and all other data expressed mean (SEM).

**Results:** The MVC (AT: 107±9, RT: 122±7, RC: 126±4 N/cm,  $P>0.05$ ) and peak muscle activation (AT: 0.60±0.09, RT: 0.65±0.13, RC: 0.65±0.08 mV,  $P>0.05$ ) were equivalent between groups. Additionally, there was no significant difference in forearm flexor thickness (AT: 4.02±0.16, RT: 4.45±0.09, RC: 4.13±0.21 cm,  $P>0.05$ ). All groups were equivalent for resting heart rate (AT: 72±4, RT: 78±3, RC: 73±3 bpm,  $P>0.05$ ), mean arterial blood pressure (AT: 92±4, RT: 96±3, RC: 94±3 mmHg,  $P>0.05$ ) and resting muscle tissue oxygen saturation (AT: 61.8±2.6, RT: 62.7±2.7, RC: 63.6±1.8 %,  $P>0.05$ ).

There were no differences between groups regarding heart rate or muscle tissues desaturation response to the sustained 100% MVC. Nonetheless, time to decline to 50% MVC was significantly longer in the RC compared to the AT (Table 1,  $P<0.05$ ).

**Table 1:** Sustained MVC (100%) fatigue protocol. \* RC versus AT,  $P<0.05$ . Mean (SEM).

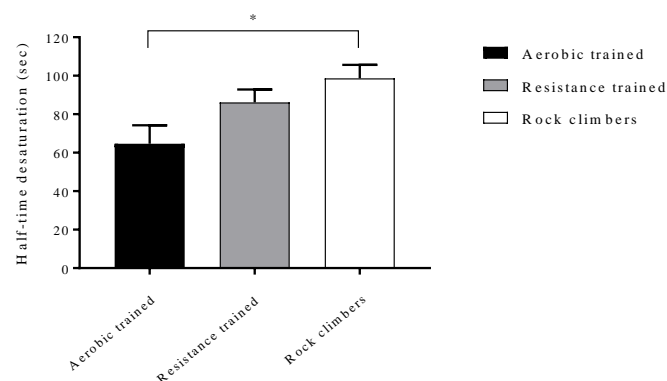
	Aerobic Trained (n=6)	Resistance Trained (n=7)	Rock Climbers (n=8)
<b>Time 50% MVC (s)</b>	35 ( $\pm$ 5)	46 ( $\pm$ 6)	54 ( $\pm$ 4)*
<b>Heart rate (bpm)</b>	106 ( $\pm$ 10)	110 ( $\pm$ 10)	108 ( $\pm$ 7)
<b>Tissue Saturation Index (%)</b>	23.2 ( $\pm$ 4.4)	19.9 ( $\pm$ 5.4)	19.8 ( $\pm$ 4.3)

There were no differences between groups regarding heart rate or muscle tissues desaturation response to sustained 40% MVC. Time to successfully sustain 40% MVC (failure to maintain target grip force) was significantly longer in the RC compared to the RT and the AT (Table 2,  $P<0.05$ ).

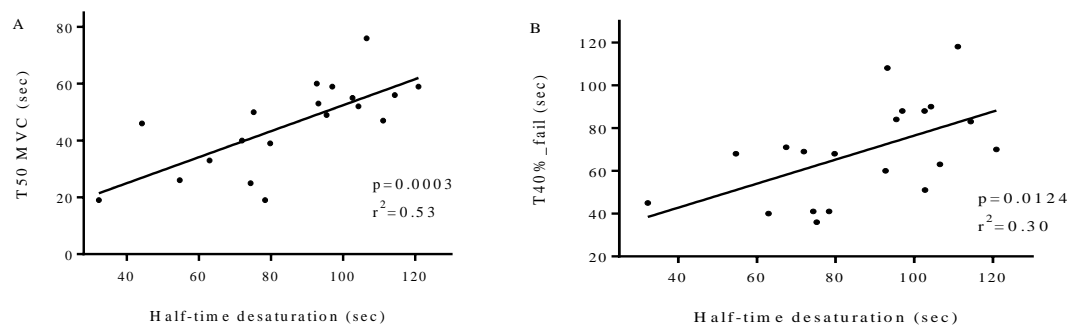
**Table 2:** Sustained 40% MVC fatigue protocol. † RC versus AT and RT,  $P<0.05$ . Mean (SEM).

	Aerobic Trained (n=6)	Resistance Trained (n=7)	Rock Climbers (n=8)
<b>Sustained time (s)</b>	56 ( $\pm$ 9)	62 ( $\pm$ 8)	84 ( $\pm$ 7)†
<b>Heart rate (bpm)</b>	96 ( $\pm$ 6)	99 ( $\pm$ 7)	100 ( $\pm$ 4)
<b>Tissue Saturation Index (%)</b>	21.2 ( $\pm$ 2.6)	22.2 ( $\pm$ 3.7)	18.1 ( $\pm$ 2.9)

Following the intermittent 40% MVC protocol [5s contraction, 5s recovery, 3mins]) RC maintained a significantly greater proportion of their MVC (AT:  $59\pm 7$  [55%], RT  $77\pm 9$  [62%], RC  $92\pm 7$  [76%] N/cm,  $P<0.05$  RC v AT) despite no difference in muscle activation between the groups ( $P>0.05$ ). Finally, when the forearm was occluded, under resting conditions, muscle tissue rapidly desaturated over the first 3 minutes of ischemia and reached steady state in all individuals by the 4<sup>th</sup> minute. The half-time desaturation (decay) was significantly longer in the RC compared to AT group (Figure 1).

**Figure 1:** Forearm occlusion response – half time desaturation during ischemia. \* $P<0.05$  RC versus AT. Mean (SEM).

There were relationships between the half-time desaturation during the forearm occlusion and the time to decline to 50% MVC ( $r^2=0.53$ ,  $P<0.05$ ) (Figure 2A) and between the half-time desaturation during the forearm occlusion and the time to task failure during the submaximal 40% MVC sustained contraction protocol ( $r^2=0.30$ ,  $P<0.05$ ) (Figure 2B).



**Figure 2:** The association between the half time desaturation during forearm occlusion and the time to **A:** fall to 50% MVC (T50 MVC), **B:** fail in the sustainment of 40% MVC.

**Discussion:** Skeletal muscle contractile fatigue is inherently linked to oxygen efficiency (Grassi *et al.*, 2015). The association between oxygen desaturation during ischemia and sustained isometric force production in the current study supports this mechanism. The RC group were able to sustain maximal and submaximal isometric forearm contractions longer than both the AT and RT groups. Previously, short term (4-6 weeks) isometric training studies have demonstrated improved fatigue resistance (Usaj, 2001) and improved oxygen efficiency of contraction (Usaj *et al.*, 2007). In rock climbers, improved muscle tissues oxygen status (Fryer *et al.*, 2016), increased skeletal muscle oxygen capacity (Fryer *et al.*, 2017) and faster re-oxygenation (Philippe *et al.*, 2012) have been the mechanisms proposed to contribute to superior contractile fatigue resistance. The current study demonstrated when grip force and muscle thickness were matched, oxygen efficiency of during ischemia is also linked to improved fatigue resistance. Most notably, the comparison to both the RT group (maximal gripping experience) and an AT group (no gripping experience), adds further insight to the adaptations of climbing *per se*. In fact, this superior fatigue resistance in the rock climbers and improved oxygen status during ischemic stress may be adaptive evidence of structural (muscle architecture), vascular (blood flow re-perfusion) or muscle fibre type (SR, mitochondrial) differences, notwithstanding the possible genetic influences. Future research, with the involvement of non-invasive ultrasound technology will seek to unpick these mechanisms.

## References

- Fryer S, et. al., (2017). Differences in forearm strength, endurance, and hemodynamic kinetics between male boulderers and lead rock climbers. *Eur J Sport Sci*, 1-7.
- Fryer S, et. al., (2016). Forearm muscle oxidative capacity index predicts sport rock-climbing performance. *European Journal of Applied Physiology* **116**, 1479-1484.
- Grassi B, et. al., (2015). Skeletal Muscle Fatigue and Decreased Efficiency: Two Sides of the Same Coin? *Exercise and Sport Sciences Reviews* **43**, 75-83.
- Philippe M, et. al., (2012). Climbing-specific finger flexor performance and forearm muscle oxygenation in elite male and female sport climbers. *European Journal of Applied Physiology and Occupational Physiology* **112**, 2839-2847.
- Usaj A (2001). The endurance training effect on the oxygenation status of an isometrically contracted forearm muscle. *European Journal of Physiology*.
- Usaj A, et. al., (2007). The influence of strength-endurance training on the oxygenation of isometrically contracted forearm muscles. *European Journal of Applied Physiology and Occupational Physiology* **100**, 685-692.