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ARTICLE

The effects of acute blood flow restriction on climbing-specific tests

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Abstract – The aim of the study was to compare climbing specific performance tests with and without blood flow restriction (BFR). Thirty one climbers (age 26.9 ± 5.5 years, height 177.2 ± 7.5 cm, weight 70.5 ± 8.3 kg, fat percentage 11.9 ± 4.1 %, climbing skill 18.9 ± 4.0 IRCRA scale) performed climbing specific grip tests measuring isometric strength (peak force, rate of force development and maximal voluntary contraction (and dynamic strength (power and peak velocity in pull-up) on a 23-mm campus rung. Further, an intermittent finger endurance (7 seconds work, 3 seconds rest at 60% of maximal voluntary contraction) test to failure was conducted. All tests were performed on two separate occasions (separated by 2–5 days) with and without blood flow restriction (200 mmHg) in a randomized order. The results demonstrated no differences in the isometric strength tests ($p = 0.496$–0.850, ES = 0.060–0.170), dynamic strength test ($p = 0.226$–0.442, ES = 0.200–0.330) or the intermittent finger endurance test ($p = 0.563$, ES = 0.160). In conclusion, no differences were observed in the maximal isometric pull-up test, dynamic pull-up test or finger endurance tests including measurements as peak force, MVC, RFD, power output, peak velocity or time to fatigue at 60% of MVC with and without BFR.

Keywords: testing, strength, power, finger, forearm

Résumé – Les effets d'une restriction aiguë du débit sanguin sur les tests spécifiques à l'escalade. Le but de l'étude était de comparer des tests de performance spécifiques d'escalade avec et sans restriction de flux sanguin. Trente et un grimpeurs (âge : 26,9 ± 5,5 ans, taille : 177,2 ± 7,5 cm, poids : 70,5 ± 8,3 kg, pourcentage de masse grasse : 11,9 ± 4,1 %, aptitude à grimper : 18,9 ± 4,0 échelle IRCRA) ont effectué des tests spécifiques d'escalade mesurant (pour les/au niveau des) doigts et des avant-bras la force isométrique (force maximale, vitesse de déploiement de la force et contraction maximale volontaire, la force dynamique (puissance et puissance et vélocité maximale, en traction) sur des anneaux de 23 mm. De plus, un test intermittent d'endurance des doigts (7 secondes de contraction, 3 secondes de repos à 60 % de la force et contraction maximale volontaire a été effectué jusqu'à épuisement. Tous les tests ont été réalisés à deux occasions distinctes (séparées par 2 à 5 jours) avec et sans restriction de flux sanguin dans un ordre aléatoire. Les résultats n'ont montré aucune différence dans les tests de force isométrique ($p = 0,496$–$0,850$, ES = 0,060–0,170), dynamique ($p = 0,226$–$0,442$, ES = 0,200–0,330) ou dans les tests intermittents d'endurance des doigts ($p = 0,563$, ES = 0,160). En conclusion, aucune différence n'a été observée dans le test de traction isométrique maximale, le test de traction dynamique ou les tests d'endurance des doigts, y compris les mesures comme la force de pointe, MVC, RFD, la puissance de sortie, la vitesse de pointe ou le temps de fatigue à 60 % de MVC avec et sans restriction de flux sanguin.

Mots clés : test, force, puissance, doigts, avant-bras

1 Introduction

The interest in climbing and performance has grown in the last decades. The association between performance and physical, psychological and tactical skills in climbing have been examined (Draper, Jones, Fryer, Hodgson, & Blackwell, 2008; Fryer, Dickson, Draper, Blackwell, & Hillier, 2013; Mermier, Janot, Parker, & Swan, 2000; Watts, 2004). It is generally accepted, that grip strength, finger endurance and the ability to generate sub-maximal force repeatedly in the fingers, elbow flexors and shoulder grid are the most important factors associated with

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climbing performance (Balas, Pecha, Martin, & Cochrane, 2012; Medernach, Kleinoder, & Lotzerich, 2015; Mermier *et al.*, 2000; Michailov *et al.*, 2018). For example demonstrated Balas *et al.* (2012) finger endurance (measured by the dead-hang test) and finger strength to be the strongest predictors of climbing performance among 205 climbers (women; $R^2 = 0.57–0.76$, men; $R^2 = 0.30–0.66$).

Lead climbing in competitions is typically performed on a 12–18 m high wall, using 20–50 climbing holds, lasting 4–6 minutes and with an average contact time to holds of eight seconds (White & Olsen, 2010). Recently, both tests and training programs have been designed to mimic these specific finger contraction with repeatedly high-intensity finger muscle contraction (60% of max in 7 seconds with 3 seconds rest) or grip endurance (40% of max, 10 seconds contraction with 3 seconds rest) (Fryer *et al.*, 2015; MacLeod *et al.*, 2007). Both finger strength and endurance training strategies have demonstrated improved finger strength and force time integral among climbers (Fryer *et al.*, 2015; MacLeod *et al.*, 2007), but no study has examined the impact of these training effects on climbing performance.

Blood lactate concentration has been associated with fatigue (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Espana-Romero *et al.*, 2009; Mermier *et al.*, 2000; Sheel, Seddon, Knight, McKenzie, & Warburton, 2003) and climbing to fatigue has resulted in blood lactate concentration of 3.2–7.0 mmol/L (Draper *et al.*, 2008; Fryer *et al.*, 2013). Further, climbing may reduce the blood flow in the forearms as repeatedly high-intensity contractions are conducted in addition to reducing the blood flow by having at least one arm above the head. Fatigue in fingers and forearms may result in decrement of climbing performance (Balas *et al.*, 2012; Espana-Romero *et al.*, 2009; Mermier *et al.*, 2000; Watts, 2004) due to reduced blood flow and accumulation of lactate. Several recovery strategies (*i.e.* hand shaking, lowering arm, mini pauses) have been used to increase the blood flow to enhance lactate clearance from type II muscles by facilitate oxidation in type I fibers or activate inactive muscles to reduce the lactate concentration (Baldari, Videira, Madeira, Sergio, & Guidetti, 2005; Valenzuela, de la Villa, & Ferragut, 2015; White & Wells, 2015). However, limited studies have been conducted with climbers (Balas *et al.*, 2016).

Blood flow restriction (BFR) has been used for decades in rehabilitation and to improve performance (Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011). Studies comparing the chronic effects of BFR training (typical 20–30% of 1RM) have demonstrated similar muscle hypertrophy, accompanied by both similar and lower increases in muscle strength compared traditional strength training approaches (>65% of 1RM) (Abe, Kearns, & Sato, 2006; Takarada, Sato, & Ishii, 2002). Acute effects of BFR have demonstrated increased muscle activation and recruitment of type II motor units (Moore *et al.*, 2004; Takarada, Takazawa, Sato *et al.*, 2000), lower blood lactate and perceived exertion, in addition to increased muscle protein synthesis and anabolic signaling (Boeno *et al.*, 2018; Fatela, Reis, Mendonca, Avela, & Mil-Homens, 2016; Pinto, Karabulut, Poton, & Polito, 2018; Wernbom, Jarrebring, Andreasson, & Augustsson, 2009). However, acute effects of BFR have demonstrated reduced performance (*i.e.* number of performed repetitions to failure) (Wernbom *et al.*, 2009).

To the authors' knowledge, no previous studies have examined the acute effects of BFR among climbers in climbing specific tests. The aim of the study was, therefore, to compare the acute effects of BFR in climbing specific grip tests (maximal isometric grip strength), power (dynamic pull-up test) and intermittent finger endurance test among climbers. We hypothesized reduced performance in the intermittent endurance test with BFR, but similar results with and without BFR in the strength tests (isometric and dynamic) due to short period of maximal effort (Fatela *et al.*, 2016; Teixeira *et al.*, 2018).

2 Material and methods

2.1 Design and procedures

To determine the possible differences in climbing specific tests performed with or without BFR, a within-participants cross-sectional study was conducted. The climbers were tested in isometric grip strength (peak force, maximal voluntary contraction, rate of force development), dynamic strength (speed and power) and endurance in two laboratory sessions. All tests were performed bilaterally on a 23-mm campus rung or fingerboard (see details later). The participants agreed to avoid climbing and climbing-related training for 48 hours before testing. The test order (with or without BFR) was randomized.

2.2 Participants

Thirty-one recreational climbers volunteered as participants. The climbers (age 26.9 ± 5.5 years, height 177.2 ± 7.5 cm, weight 70.5 ± 8.3 kg, fat percentage 11.9 ± 4.1 %), highest accomplish climbing grade (red-point) no less than 7a (IRCRA 17) for men and 6b (IRCRA 13) for women to be included in the analyses. The mean self-reported accomplished climbing grade within the last six months was 19.3 ± 3.6 (IRCRA) ranging from an advanced level to higher elite level (Draper *et al.*, 2016). The testing procedures were confirmed with the Regional Committees for Medical Health and Research Ethics in Norway (2018/1345 REK Sør-øst D) and conformed to the standards of treatment of human participants in research outlined in the 5th Declaration of Helsinki. All participants were informed orally and in writing before giving their written consent to participate.

2.3 Measures and procedures

All participants were familiar with the testing procedures using the campus rung (23 mm deep, Metolius Climbing, Bend, Oregon, USA, Fig. 1A) and the fingerboard (Beastmaker 1000 series, Beastmaker Limited, Leicester, United Kingdom, Fig. 1B). Before each session,

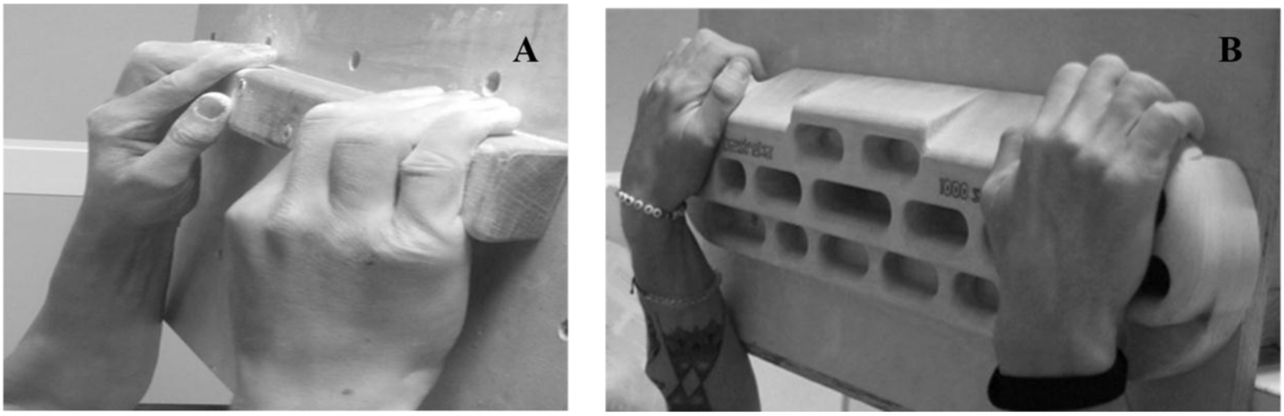

Fig. 1. (A, B) Campus rung and fingerboard used in the testing.

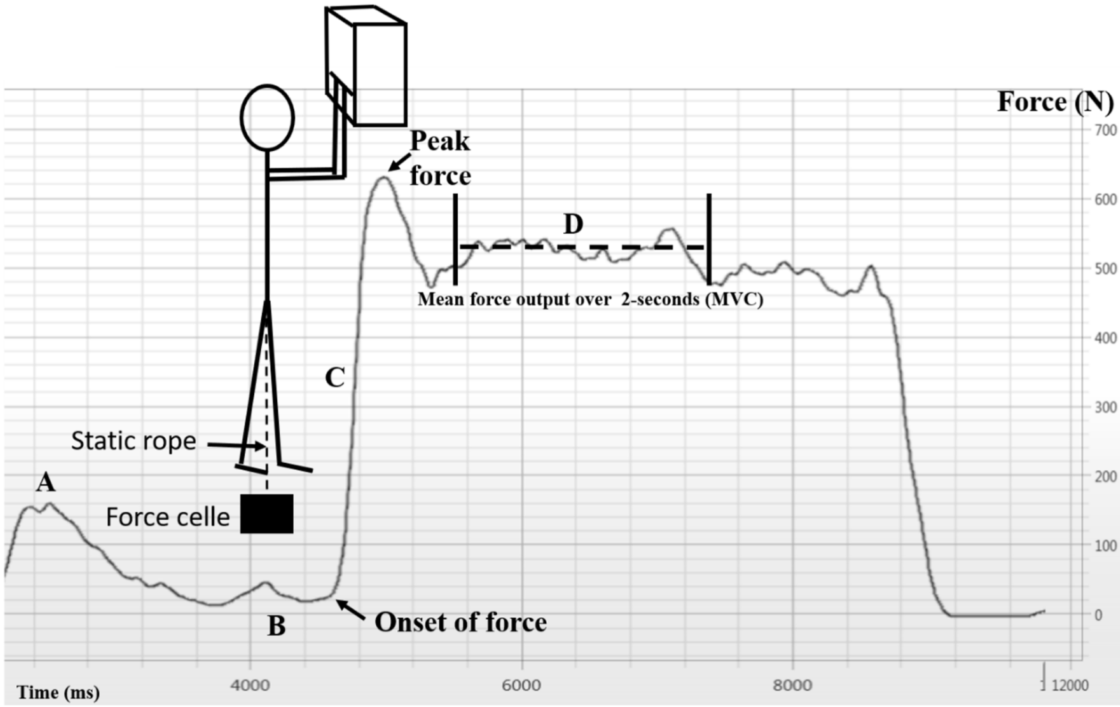

Fig. 2. A typical example of a force curve in the isometric test.

a standardized warm-up was conducted. The participants performed 15 minutes of bouldering and traversing (light to medium intensity). After the warm-up, the order of the tests were isometric strength, dynamic strength and finger endurance. Pauses of 3–5 minutes separated the three tests. In the isometric and dynamic tests, three attempts (separated by 1–2 minutes) were conducted. In the finger endurance test, only one attempt was conducted due to fatigue.

2.4 Isometric test

The participants performed all test wearing a climbing harness. A force cell (Ergotest Innovation A/S, Porsgrunn, Norway) was attached to the floor and to the harness using an adjustable static rope (Fig. 2). The participants were asked to perform a pull-up hanging on the rung with an open crimp (no thumb was allowed). When the elbow and shoulder angle was 90 degrees, the length of the rope was adjusted (Fig. 1A). The elbow angle was measured using a goniometer along humerus and ulna. The angle was controlled before starting the test. The force output was calculated as the force generated and adding the body weight of the climbers.

The isometric grip strength test started with the participants performing a pull-up until the rope stopped further movement upwards (A in Fig. 2). This position was maintained for a brief period (0.5–1.0 seconds, B in Fig. 2). Before the participants tried to continue the pull-up (C in Fig. 2) with maximal effort and as rapid as possible. The maximal force was obtained for at least 2 seconds, but the participants were encouraged to continue generating force

Fig. 3. Intermittent finger endurance test.

until a distinct drop of force was observed (see Fig. 2). Three force derivatives were measured in each attempt:

(1) the initial peak of force was calculated as the highest force generated (*i.e.* peak force, see Fig. 2);

(2) after the first peak, the participants were instructed to continue generate maximal force (D in Fig. 2). The maximal voluntary contraction force (MVC) was calculated as the highest mean force generated over a 2 seconds window (D in Fig. 2);

(3) the RFD was calculated from the onset of force generation to peak force (see Fig. 2). To calculate and identify these different periods, software version 10.5 from Ergotest Innovation A/S (Porsgrunn, Norway) was used. The best attempt in the isometric strength test was used in further analyses.

2.5 Dynamic test

A dynamic pull-up was used as the measurement of dynamic strength. Before the test, a linear encoder (Ergotest Innovation A/S, Porsgrunn, Norway) was attached to the climbing hardness to measure vertical displacement and velocity. The tested started when the participants hang vertical with fully extended elbows on the jug holds (largest holds) on a fingerboard (Beastmaker 1000 series). When ready, the subject performed a pull-up as fast as possible and stopped when the eyes were higher than the holds. The mean and peak power (body weight × lifting velocity) and mean and peak lifting velocity were calculated and identified using software version 10.5 from Ergotest Innovation A/S (Porsgrunn, Norway). All participants had three attempts and the attempt with the highest power output was used in further analyses. 1–2 minutes pauses separated each attempt.

2.6 The finger endurance test

The intermittent finger endurance test was performed seated with a 90-degree angle in the elbows (see Fig. 3). The participants used an open crimp grip (without using the thumb) on a 23 mm deep campus rung used in the isometric tests. The rung was attached to a costume built finger-training rack. A force cell (Ergotest Innovation A/S, Porsgrunn, Norway) measured the participants' finger flexion force. To avoid movement in the elbows (*i.e.* using the back muscles to generate force), a barbell was placed between the elbows and the abdominal region. The distance from the barbell and campus rung was individual adjusted so that only distal phalanges reached the rung. When ready, the participants performed three maximal contractions lasting 3–5 seconds and separated by 1–2 minutes. The mean force over a 2-second window was used as the climbers' maximal finger strength. During the endurance test, the participants had to generate minimum 60% of the maximal finger strength during the work periods. These periods lasted for 7 seconds and were accompanied by 3 seconds rest (7:3 ratio) (White & Olsen, 2010). If the participants generated less than 60% of maximal finger strength over a 1-second window, the test was terminated (Medernach *et al.*, 2015). A monitor providing feedback of the participants' force generation was placed in front of the subject (see Fig. 3). The threshold (60% of maximal) was marked as a horizontal line on the screen. The Beastmaker application (Beastmaker 1000) was used to inform the climbers of the rest and contraction times. In addition, the test leaders performed oral instructions (*i.e.* count down). The total working time to exhaustion (*i.e.* the pauses were not included) was used in further analyses (Medernach *et al.*, 2015).

The procedures of the three tests (isometric strength, dynamic strength and finger endurance) were similar with and without BFR. The order was randomized by drawing. B-strong BFR training system was used to reduce the blood flow of the forearms. The bands (width 5.0 cm) were placed as proximately as possible on the upper arm according to the manufactory recommendations. A 200-mmHG pressure was applied (Loenneke *et al.*, 2011; Sumide, Sakuraba, Sawaki, Ohmura, & Tamura, 2009; Wernbom, Augustsson, & Thomee, 2006) before each of the three tests and controlled before starting each trail. Between the tests, the pressure was relieved.

2.7 Statistical analyses

Differences between the groups were identified using a Student's *t*-test. SPSS statistical software (Version 25.0, SPSS Inc., Chicago, IL, USA) was used for the analyses. For statistical significance, the alpha level was set at 0.05. All results are presented as the mean ± standard deviation and Cohen's effect size (ES). An ES of 0.2 was considered small, 0.5 medium and 0.8 large (Cohen, 1988).

3 Results

There were no differences in the isometric strength tests, dynamic strength tests or finger endurance test between the two conditions ($p = 0.226$–0.806, ES = 0.060–0.330). All details are presented in Table 1.

4 Discussion

The aim of this study was to compare the acute effects of BFR in climbing performance tests. The present study

Table 1. Results of the isometric strength test, dynamic strength test and finger endurance with or without blood flow restriction (BFR).

		No BFR	BFR	*p*-values	Effect size
Isometric strength test	Peak force (N)	1167 ± 198	1157 ± 231	0.850	0.06
	RFD (Ns^{-1})	1305 ± 567	1424 ± 782	0.496	0.17
	MVC (N)	1029 ± 189	1016 ± 178	0.781	0.10
Dynamic strength test	Mean power (W)	602 ± 169	567 ± 180	0.442	0.20
	Peak power (W)	1066 ± 307	978 ± 315	0.284	0.28
	Peak velocity (ms^{-1})	1.52 ± 0.41	1.39 ± 0.37	0.226	0.33
Finger endurance	Time to exhaustion (s)	99 ± 30	94 ± 33	0.563	0.16

demonstrated no significant differences between the two conditions in the isometric strength test, dynamic strength tests or in the intermittent endurance test.

As hypothesized, no differences were observed between the two conditions in the strength tests. The lack of difference is probably caused by the duration of the test (<5 seconds with maximal effort). With a duration of approximately 5 seconds, the lactate concentration or any other metabolites would probably not accumulate to a level that could affect the performance (Tillaar, Saeterbakken, & Ettema, 2012). Still, the pressure was relieved between the three attempts in each test (isometric and dynamic test). One might speculate that the repeated maximal effort might lead to an accumulation of blood lactate (Pinto *et al.*, 2018) and cause peripheral fatigue using BFR. However, the results do not support the speculation. In comparison, researchers have observed problems performing more than 2–3 sets of resistance training to failure with a high pressure (Pope, Willardson, & Schoenfeld, 2013; Wernbom *et al.*, 2013). However, the climbers only performed three MVC or dynamic pull-ups. Based on the results, BFR did not have a negative impact on the climbing performance tests measured over a short period of time with maximal effort. Importantly, climbers have greater grip strength and the ability to perform repeatedly sub-maximal grip contractions than non-climbers (Balas *et al.*, 2012; Grant *et al.*, 2001; Grant, Hynes, Whittaker, & Aitchison, 1996). It could be speculated that years of climbing has made the participants in the present study, tolerant to removing and buffering blood lactate in addition being used to climb with muscles in ischemia. Furthermore, both test conditions (with and without BFR) probably lead to ischemia in the involved muscles and the two testing conditions may therefore be quite similar which may have resulted in the non-significant differences between them.

High-intensity resistance training (>70% of 1RM) causes the increased intrathoracic pressure and mechanical compressions, which reduces the blood, flow (Lentini, McKelvie, McCartney, Tomlinson, & MacDougall, 1993; MacDougall *et al.*, 1992). To include BFR with maximal isometric and dynamic contractions in the present study may therefore make the two testing conditions almost identical. In the pilot testing of the present study, the isometric tests (without BFR) increased in pressure to 110–130 mmHg. These values are above 50% of the BFR pressure used in the experimental tests. Moderate vascular restriction (~100 mmHg) have demonstrated muscular hypertrophy with resistance as low as 20% of 1RM for athletes, patients and elderly (Fry *et al.*, 2010; Takarada, Nakamura *et al.*, 2000; Takarada, Takazawa, & Ishii, 2000; Takarada, Takazawa, Sato *et al.*, 2000) even after only two sessions (Takarada *et al.*, 2002; Takarada, Tsuruta, & Ishii, 2004). Still, the present study only compared maximal isometric and dynamic strength with and without BFR and demonstrated no harms or benefits. The isometric and dynamic strength results in the present study were supported by previous studies, which also reported no acute effects of BFR on strength tests (Fatela *et al.*, 2016; Teixeira *et al.*, 2018).

Despite increasing the duration of the test by 5 seconds without BFR, no differences were observed in the time to exhaustion between the conditions in the endurance test. The findings were in contrast to our hypotheses. It could be speculated whether the total duration of the test was to short (approximately 95–100 seconds). Longer duration (*i.e.* lower intensity) may have increased the lactate concentration, accumulation of metabolites and recruitment of fast twitch fibers (Loenneke *et al.*, 2011). All of the abovementioned factors that may in theory reduce BFR performance during the endurance test, but not in the present study. Still, the intensity used in the intermittent test, may have been too high. This speculation is supported by Wernbom *et al.* (2006) who demonstrated reduced performance (repetition to fatigue) examining 20–40% of 1RM to failure, but not at higher intensities (>50% of 1RM). Similarly, Hisaeda, Shinohara, Kouzaki, & Fukunaga (2001) demonstrated no differences between BFR and no BFR in isometric leg extension at 50% of MVC. Importantly, both test conditions may have led to ischemia in the forearm muscles due to the seven contractions. In theory, BFR may reduce the capacity to remove the accumulation of blood lactate and increased muscle activation and recruitment of type II motor units (Moore *et al.*, 2004; Takarada, Takazawa, Sato *et al.*, 2000), which lead to fatigue. This mean that as the test continues, the forearm muscles will be in a constant ischemia. However, without BFR, the blood flow will continue in the 3 seconds pauses and therefore delay some of the factors resulting to fatigue and avoid the constant ischemia. However, and probably as result of the testing procedures using 60% of MVC (*i.e.* relative short overall test time until fatigue), no significant differences were observed between the two conditions. Still, we encourage researcher to add spectroscopy or pulse oximetry to control the two conditions in further studies.

Another plausible explanation is the local adaptions in fingers and forearms among climbers. Climbers are superior in finger strength and/or endurance compared to non-climbers (MacLeod *et al.*, 2007). One might speculate that specific finger and forearms adaptions after years of climbing, could reduce the peripheral fatigue. For example, previous studies not including climbers have demonstrated increased peripheral fatigue with BFR (Schoenfeld, 2013; Teixeira *et al.*, 2018). In addition, the present study examined relatively small muscles in contrast to previous studies examining the legs (MacDougall *et al.*, 1992).

The study have some limitations, which need to be addressed. First, only climbers on advanced to elite performance level was recruited. Therefore, the results may therefore not be generalized to other population of climbers. Second, the aim of the study was to examine the acute effects of BFR on climbing specific tests. The chronic effects of BFR in climbing were not examined and no conclusion of the chronic effects can be generalized from the present study. Thirdly, no measurements of muscle protein synthesis, blood lactate concentration, spectroscopy, pulse oximetry or anabolic signaling were conducted. Further, electromyography was not conducted to examine muscle recruitment. Lastly, the force generated during the dynamic pull-ups were not measured and the peak power output may have been reduced as the participants stopped the upward movements in eye height instead of doing an arm-jump. It is possible that there were other acute effects of BFR, but the present study did not include these measurements.

5 Conclusion

In conclusion, no differences were observed in the maximal isometric pull-up test, dynamic pull-up test or finger endurance tests including measurements as peak force, MVC, RFD, power output, peak velocity or time to fatigue at 60% of MVC with or without BFR. Therefore, in future interventions comparing climbing specific training with and without BFR, it seems sufficient to perform the tests without BFR as long as they focus on maximal effort over a limited period of time.

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