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Effect of interval bouldering on hanging and climbing time to exhaustion

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Running head

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The authors declare no conflict of interest and no sources of funding. The authors do not have relationships to companies or manufacturers who will benefit from the results of the present study. All participants gave written informed consent and were informed of their right to leave the study at any stage. The study protocol had ethical approval from the German Sport University Cologne.

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Abstract

Indoor bouldering consists of low height climbing sequences completed without ropes on artificial walls with landing mats for protection. Although bouldering is increasingly popular and competitive, scientific research remains sparse and information on ideal training regimens is limited. The aim of the present study was to investigate the effect of interval bouldering on hanging and climbing time to subjective exhaustion. Twenty-four male highly advanced boulderers (25.2 ± 4.8 yrs; 1.77 ± 0.07 m; 69.1 ± 5.3 kg; 6.8 ± 3.1 yrs climbing; 7b Fontainebleau bouldering ability) were randomly allocated to a 4-week interval bouldering (IB with n = 12) and conventional bouldering (CB with n = 12) training regimen. Pre- and post-tests consisted of intermittent finger hangs (IFH) and climbing time to exhaustion (CTE). Results indicate significant higher IFH times after 4-week regimen for IB (+27.3 ± 18.4 s, t_{11} = -5.16, $P < .001$), but not for CB (+ 4.9 ± 11.5 s, t_{11} = -1.47, $P = .168$). Moreover, a significant higher CTE was displayed for IB (+ 36.2 ± 14.1 s, t_{11} = -8.85, $P < .001$), but not for CB (6.1 ± 19.3 s, t_{11} = -1.09, P =.298). These findings suggest that IB is a highly effective method to increase hanging and climbing time to exhaustion in competitive bouldering.

Keywords: *Climbing, fingerboard, grip endurance, strength training, intermittent training*

1. Introduction

Competitive bouldering is an independent discipline of sport climbing undertaken without ropes at low height artificial walls with landing mats to minimise injury risks (Fanchini, Violette, Impellizzeri, & Maffiuletti, 2013; Hatch, 2013; La Torre, Crespi, Serpiello, & Merati, 2009). Bouldering competitions organized by the International Federation of Sport Climbing consist of a qualification (5 boulders), a semi-final (4 boulders), and final round (4 boulders) with all boulders completed in as few attempts as possible (Hatch, 2013). Despite the ongoing popularization and professionalization, scientific research in bouldering is limited and the increasing number of competitions organized at regional, national, and international level has raised questions on how to maximize individual performance (Josephsen et al., 2007; Macdonald & Callender, 2011; White & Olsen, 2010). Numerous training methods published in coaching manuals and climbing magazines have not been investigated empirically and experimental findings from sport climbing research are hardly applicable in bouldering since both climbing disciplines differ substantially in terms of physical, technical, and tactical demands (Fanchini et al., 2013; Josephsen et al., 2007; Macdonald & Callender, 2011; White & Olsen, 2010).

The focus of competitive bouldering relies on short and strenuous climbing sequences with maximum grip strength as primarily key factor. Macdonald and Callender (2011) found finger strength in highly accomplished boulderers significantly greater (P = .001) compared to aerobically trained non-climbers and superior to that of elite lead climbers. More recently, Fanchini et al. (2013) measured greater finger strength in highly advanced boulderers in contrast to lead climbers of equal ability levels. However, as attempt duration varies in view of the complexity, the style, and the length of a boulder, grip endurance could be considered a key factor not only to allow the successful single attempt but especially to facilitate a quick recovery between attempts and to support the total volume of work throughout the competition (Hörst, 2008; MacLeod, 2010; White & Olsen, 2010). White and Olsen (2010) found successful ascents in elite competitive bouldering lasting on average 39.5 ± 4.1 s and athletes attempting a problem 2,8 ± 1,7 times in accordance to the individual climbing ability and the tactical approach. In addition, the rotation period system in the qualification and semi-final imposes that all problems have to be climbed in a prescribed order with a fixed climbing time of five minutes for each boulder and a resting period between two boulders equal to the climbing time (Hatch, 2013). From this perspective, it seems evident that competitors are given limited recovery time between two problems and that rapid recovery post attempt is of outstanding importance.

A popular strategy to increase grip endurance in competitive bouldering that has not been investigated is interval bouldering which involves repeating laps on moderately difficult boulders with a climbing-to-rest ratio of 1:1 to 1:2 (Hörst, 2008; MacLeod, 2010). The present study, therefore, aims to investigate the training effects of four-week interval bouldering on hanging and climbing time to subjective exhaustion in highly advanced competitive boulderers.

2. Methods

Participants

Twenty-four male highly advanced competitive boulderers volunteered in the study. Characteristics, bouldering experience, and bouldering ability levels of the subjects are listed in Table I. All participants had to be at least 18 years old and were drawn from local climbing clubs and commercial climbing centres. Before participating in the study, participants completed a physical activity and health history questionnaire to ensure homogeneous samples and to minimize injury risks. Only healthy boulderers with no recent injury history and a minimum bouldering experience of three years were included. Moreover, self-reported bouldering ability, which is a widespread and accurate assessment method in climbing (Draper et al., 2011), was set at a minimum of 7a Fb (Fb corresponds to Fontainebleau which is a rating scale used in bouldering) in the past four months to ensure participants of advanced bouldering ability levels. The investigation was carried out in-season but participants had not to be engaged in a periodized bouldering training in the last four weeks prior the investigation in order to minimize the influence of past training effects. All participants were informed of their right to leave at any stage and provided written informed consent. The study protocol had ethical approval from the University. [Table I about here]

Experimental Design

Participants were randomly attributed to a four-week interval bouldering (IB with n = 12) and conventional bouldering (CB with n = 12) training regimen. The length of the training period was determined in response to suggestions made in coaching manuals (Hörst, 2008, MacLeod, 2010) and in accordance to the findings of Medernach (2012), who investigated the largest hang time increases in a 12-week fingerboard regimen occurring in the first four weeks. Pre- and post-tests for data collection of about 60 min duration were accomplished at the same time of day (18.00-19.00) with a minimum rest period of 48 hrs prior to testing. All participants were prompted to maintain their daily eating and sleeping habits. Furthermore, no alcohol consumption should have occurred 24 hours and caffeine consumption two hours prior to data collection. All participants were supervised by the same examiners throughout all testing sessions. Participants were prescribed only White Gold Loose Chalk of the manufacturer Black Diamond (Utah, USA) and a brush of the manufacturer Lapis (Ljubljana, SLO) to clean the grips before data collection in order to guarantee standardized grip conditions. Individual warm-up was of light bouldering (10 - 12 easy bouldering problems) and a familiarization trial for all tests with a rest period of 7 min after warm-up. To guarantee standardized test implementations, tests were carried out in a standardized order and participants were verbally encouraged until voluntary exhaustion. One attempt was recorded for each endurance test with a stopwatch (accuracy of 0.3 s) and a standardized rest time between tests of 7 min.

Perceived Physical State, Temperature, and Body Characteristics

Pre- and post-tests involved the Perceived Physical State questionnaire (PEPS) which is a valid 20-item scale to assess individual perceived activation ($PEPS_{activation}$) and training ($PEPS_{training}$) state (Kleinert, 2006). Since temperature can influence hanging times to exhaustion (MacLeod, 2010), room temperature was measured using Lufft C200 thermometer (Lufft, Fellbach, GER) with an accuracy of 0.3 °C. Participants were weighted in shorts and T-shirts without shoes to the nearest 0.1 kg using Seca 760 scale (Seca GmbH, Hamburg, GER) and height was measured without shoes to the nearest 0.5 cm using Seca 213 stadiometer (Seca GmbH, Hamburg, GER).

Intermittent Finger Hangs

Climbing and bouldering require intense intermittent efforts making pure isometric endurance tests unspecific (La Torre et al., 2009; Quaine, Vigouroux, & Martin, 2003; Schöffl, Möckel, Köstermeyer, Roloff, & Küpper, 2006). Grip endurance was therefore assessed via intermittent isometric finger hangs (IFH) with an accuracy of 0.3 s on a 30 mm deep crimp grip of the fingerboard Alien, Freestone (FRA), fixed at 120° beyond vertical (Figure 1). The hang-to-rest ratio of 2 : 1 with a hanging time of 8 s and a rest time of 4 s were chosen based on the study of White and Olsen (2010), who found average hand contact times during competitive bouldering of 7.9 s. [Figure 1 about here]

Climbing time to exhaustion

Climbing time to exhaustion (CTE) was found to be a climbing performance determinant in high-level sport climbers and therefore adequate to assess intermittent isometric endurance in combination with upward movements (España-Romero et al., 2009). CTE was assessed on a 4.10 m high and 2.10 m wide bouldering wall set at 120° beyond vertical and equipped with four climbing grips and six footholds of 7 cm edge depth (Figure 2). The four grips were campus rungs of (A) 20 mm, (B) 30 mm, (C) 45 mm, and (D) 45 mm edge depth from the manufacturer MR Climbing (La Rochette, FRA). The grips were set in *ABCD* order with 60 cm space between each rung. Participants started on grip (A), climbed up without relief time to grip (B), (C), and (D), and were told after reaching grip (D) to jump down and repeat the pattern as often as possible, with no rest period between the repetitions. In order to guarantee a specific test procedure and a standardized climbing speed, participants were told to remain in a sustained isometric position for 4 s on grip (A), 6 s on grip (B), 8 s on grip (C), and 10 s on grip (D). Climbing speed and time of a sustained isometric position were measured with a Sigma SC 6.12 stopwatch (Sigma, Rödemark, GER) to an accuracy of 0.3 s and communicated via acoustic signal to the subjects. Subjects moved from grip (A) to grip (B) with the right hand and changed the hands alternately up to grip (D). The climb was designed such that one pattern was of about 30 s duration with a mean hand contact time of about 7 s which is in accordance with the results of White and Olsen (2010) for competitive bouldering. Exhaustion was defined as the inability to keep on climbing despite verbal encouragement. [Figure 2 about here]

Training contents

Qualified climbing coaches supervised the participants to guarantee accurate training guidance and all participants performed individual warm-up and cool down (bouldering easy problems) for each training session. IB and CB were both undertaken three times per week with each session of about 150 min duration and a total number of 12 sessions. IB consisted of interval patterns involving (a) four, (b) six, (c) eight, and (d) ten climbing movements with each pattern repeated four times with no rest between repetitions and 7 min of recovery after each set. Total climbing duration per set was about 1 - 4 minutes in accordance to the number of climbing movements and a total of three sets per pattern were accomplished. Problems were defined to be homogeneous without difficult moves to prevent participants from slipping off before local fatigue of the forearms occurred and participants were instructed to climb at normal speed. The intensity of the climbs was chosen in order to guarantee post effort individual exhaustion of the forearm muscles. In contrast, the CB group performed bouldering problems (25 - 35 attempts per training session) at individual ability level with on average 4 - 8 handholds per boulder, a bouldering time less than 1 min and a complete recovery time after each set of 5 min. Participants of both IB and CB were not allowed to perform any additional training regimen to the training contents of the present study.

Data analysis

Statistical analyses were performed using IBM SPSS Statistics 20 (Armonk, USA) and Microsoft Excel 2007 (Redmond, USA). All variables were assessed for normality of distribution using one-sample Kolmogorov-Smirnov test, skewness and kurtosis *z*-values, and visual inspection of normal Q-Q plots. All variables within the study showed an approximately normal distribution and data are reported as means and standard deviations. An alpha level of .05 (2-tailed) was set to accept statistical significance for all inferential tests. Paired samples *t*-tests were used to compare means between pre- and post-tests and a multivariate analysis of variance (MANOVA) with Bonferroni post-hoc comparison to investigate differences between IB and CB. Intra-class correlation coefficient (ICC) and paired samples *t*-tests were calculated to determine the reliability and consistency of the endurance tests via test-retest format. Pearson product-moment correlation coefficient was calculated in order to identify the relationship between IFH and CTE.

3. Results

None of the 24 participants had to abandon the study. Descriptive data are displayed in Table II. Body weight did not change significantly between pre- and post-tests for both IB (t_{11} = 1.84, *P* = .094) and CB (t_{11} = 1.48, *P* = .166). Moreover, no significant differences in body weight were investigated between IB und CB in pre- [*F*(1,22) = 0.73, *P* = .789] and post-test [*F*(1,22) = 0.26, *P* = .617]. Bouldering ability level in pre-test did not differ significantly between IB and CB [*F*(1,22) = 4.00, *P* = .058]. $PEPS_{training}$ and $PEPS_{activation}$ in pre- and post-test did not differ significantly between IB und CB [*F*(1,22) = .64, *P* = .432, *F*(1,22) = 2.07, *P* = .164, *F*(1,22) = 0.31, *P* = .584 and *F*(1,22) = .49, *P* = .490] with, however, significant increases after the 4-week regimen for $PEPS_{training}$ in both IB (t_{11} = -3.12, *P* = .007) and CB (t_{11} = -4.49, *P* = .001), but not for $PEPS_{activation}$ score (IB: t_{11} = -1.05, *P* = .318 and CB: t_{11} = -1.03, *P* = .323). Room temperature did not change significantly between pre- and post-test for IB (t_{11} = .52, *P* =.613), but for CB (t_{11} = 4.52, *P* =.001). In addition, room temperature in pre- and post-test significantly differ between IB and CB [*F*(1,22) = 131.2, *P* < .001 and *F*(1,22) = 86,4, *P* < .001]. Significant higher IFH times were displayed after the 4-week regimen for IB (t_{11} = -5.16, *P* < .001), but not for CB (t_{11} = -1.47, *P* = .168) and CTE increased significantly for IB (t_{11} = -8.85, *P* < .001), but not for CB (t_{11} = -1.09, *P* =.298). Moreover, significant higher increases in CTE [*F*(1,22) = 15.04, *P* = .004] and IFH [*F*(1,22) = 18.89, *P* < .001] were investigated for IB when compared to CB. Intra-class correlation coefficient for test-retest (test was accomplished 48 hrs before the pre-test whereas the retest was equal to the pre-test) showed a high reliability for IFH (*r* = .862, *P* < .05) and CTE (*r* = .988, *P* < .05) and paired samples *t*-tests showed non-significant differences between pre- and post-tests for IFH (*P* = .475) and CTE (*P* =.946). Moreover, Pearson product-moment correlation coefficient showed a significant linear correlation between IFH and CTE (*r* = .873, *P* = .001).

4. Discussion

The present study aimed to investigate the effects of four-week IB and CB on grip endurance in highly advanced boulderers. To the best of our knowledge, this is the first study to investigate hanging and climbing times to subjective exhaustion in bouldering.

Participants of the present study had similar body mass and height values when compared to the advanced boulderers in the study of Macdonald and Callender (2011) and height, body mass, and BMI were of equal scores when compared to aerobically trained non-climbers and lead climbers (Macdonald & Callender, 2011; Philippe, Wegst, Müller, Raschner, & Burtscher, 2011; Schöffl et al., 2006).

Major findings of the present research are the significant increases in IFH (+27 s) and CTE (+36 s) after four weeks of interval bouldering (figure 3) when compared to the non-significant increases for CB (+5 s and +6 s, respectively). We believe that longer IFH times and a higher CTE may have a positive influence on bouldering performance as competitors might be able to persevere through longer sequences and profit from an accelerated recovery post effort. Non-significant increases of IFH and CTE in CB can be attributed to the low height and the average 4 - 8 handholds per boulder (Hatch, 2013; Hörst, 2008). Although the explanations for the increased hanging and climbing time to fatigue were not investigated in the present study, it appears that grip endurance gains may be explained by a greater forearm re-oxygenation and an enhanced lactate removal during resting through a higher muscle capillary density and a greater vasodilator response (Hörst, 2008; MacLeod, 2010; MacLeod et al., 2007; Quaine et al., 2003; Watts, 2004). [Figure 3 about here]

Our results are in accordance with Medernach (2012) who found in intermediate lead climbers hanging times to exhaustion of approximately 30 s after a 12-session endurance fingerboard regimen. López-Rivera and González-Badillo (2012) investigated two different grip strength and endurance training regimens of four-week duration in lead climbers and found, however, considerably lower mean grip endurance gains of 5.97 s and 7.78 s when compared to the results of the present study. Advanced boulderers have generally a lower grip endurance compared to lead climbers of equal ability levels since competitive bouldering involves shorter attempt durations (White & Olsen, 2010) and it appears that grip endurance occur therefore much faster in boulderers when compared to lead climbers. It is, however, likely that the intermittent isometric test design of the present study may be more appropriate when compared to the pure isometric testing of López-Rivera and González-Badillo (2012). Furthermore, a comparison to the results of our study is limited since the authors involved an experimental design in which participants were performing multiple tasks in addition to the grip strength and endurance training and therefore the cause of any improvement was not sufficiently isolated.

Non-significant differences in ability level, body weight and $PEPS_{activation}$ as well as standardized test implementations and similar training volumes suggest that the observed increases in CTE and IFH are very unlikely to be attributable to external factors, but mainly due to the prescribed training stimulus. Although the present study was carried out in-season, it is unlikely that delayed training effects from past training inputs have influenced the results since participants were not allowed to perform any specific bouldering training in the last four weeks prior the investigation. Moreover, the number of training sessions per week during the investigation (three sessions per week) corresponded approximately to the common number of training sessions per week before the investigation, so that additional stimuli can be excluded as explanation for the increases in hanging and climbing time to exhaustion. However, significant higher $PEPS_{training}$ scores for both IB and CB in the post-test demonstrate that participants estimated themselves in a better training shape after the training regimen and it remains therefore unclear to what extent psychological factors may have potentially caused variability in the results. Moreover, the significant differences in room temperature between IB and CB as well as between pre- and post-tests may have influenced hanging and climbing times to exhaustion. However, we believe that this influence of the room temperature may be disregarded, since the differences between IB (15.2 °C and 15.1 °C) and CB (17.7 °C and 16.6 °C) are minor.

When interpreting the present results, it must be pointed out that competitive bouldering involves in addition to grip endurance a complex interaction of multiple variables such as climbing skills, individual tactic, flexibility, balance, and psychological aspects (Hörst, 2008; MacLeod, 2010) which were not taken into account. Several investigations demonstrate for instance that active recovery through walking and ergometer cycling at 30 - 40 Watt as well as cold water immersion are practical strategies to combat peripheral fatigue and could be beneficial to subsequent bouldering trials (Draper, Bird, Coleman, & Hodgson, 2006; Heymann, De Geus, Mertens, & Meeusen, 2009). In conclusion, future studies are necessary to investigate the impact of CTE and IFH increases during competitive bouldering in interaction with other variables.

5. Conclusion

According to the main findings of the present study, interval bouldering is a highly effective method to increase hanging and climbing time to individual exhaustion in competitive bouldering. In contrast, conventional bouldering is not an adequate grip endurance training method because of the limited number of climbing moves.

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Tables

Table I. Characteristics, experience, and bouldering ability levels for the Interval Bouldering (IB) group and the Conventional Bouldering (CB) group.

	IB (n = 12)	CB (n = 12)
Age (yrs)	25.4 ± 5.3	25.0 ± 4.5
Height (m)	1.76 ± 0.08	1.77 ± 0.06
Weight (kg)	68.8 ± 5.3	69.4 ± 5.4
BMI	22.3 ± 1.5	22.1 ± 1.2
Experience (yrs)	7.0 ± 3.2	6.5 ± 3.2
Frequency (days / week)	4,1 ± 0,6	4,2 ± 0,4
Mean climbing ability	7b Fb	7b Fb

Values are means ± s; Fb (Fontainebleau rating scale).

Table II. Descriptive data for body characteristics, PEPS, room temperature, IFH, and CTE.

Variable	IB (*n* = 12)		CB (*n* = 12)	
	pre	post	pre	post
Body weight (kg)	68.8 ± 5.3	67.9 ± 5.2	69.4 ± 5.4	68.9 ± 4.6
$PEPS_{activation}$	3.9 ± 1.0	4.1 ± 0.6	4.0 ± 0.6	4.3 ± 0.5
$PEPS_{training}$	3.5 ± 0.8	4.2 ± 0.6 †	3.9 ± 0.4	4.4 ± 0.3 †
Room temperature (°C)	15,2 ± 0.6	15,1 ± 0.2	17,7 ± 0.4‡	16,6 ± 0.5 †‡
Intermittent finger hangs (s)	93.1 ± 39.0	120.4 ± 39.8 †	94.6 ± 35.6	99.5 ± 33.4 ‡
Climbing time to exhaustion (s)	93.4 ± 24.3	129.6 ± 24.7 †	92.4 ± 22.1	98,5 ± 14.7 ‡

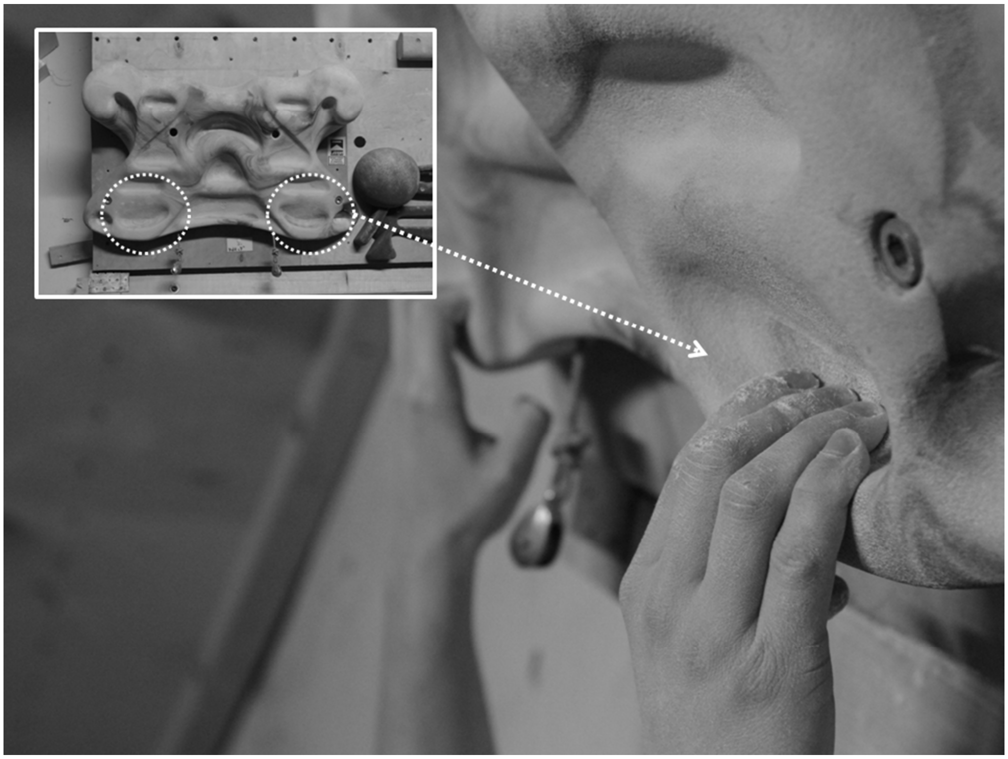
Values are means ± s.
† significant (P < .05) differences between pre- and post-test
‡ significant (P < .05) differences between FB and BL.

Figures

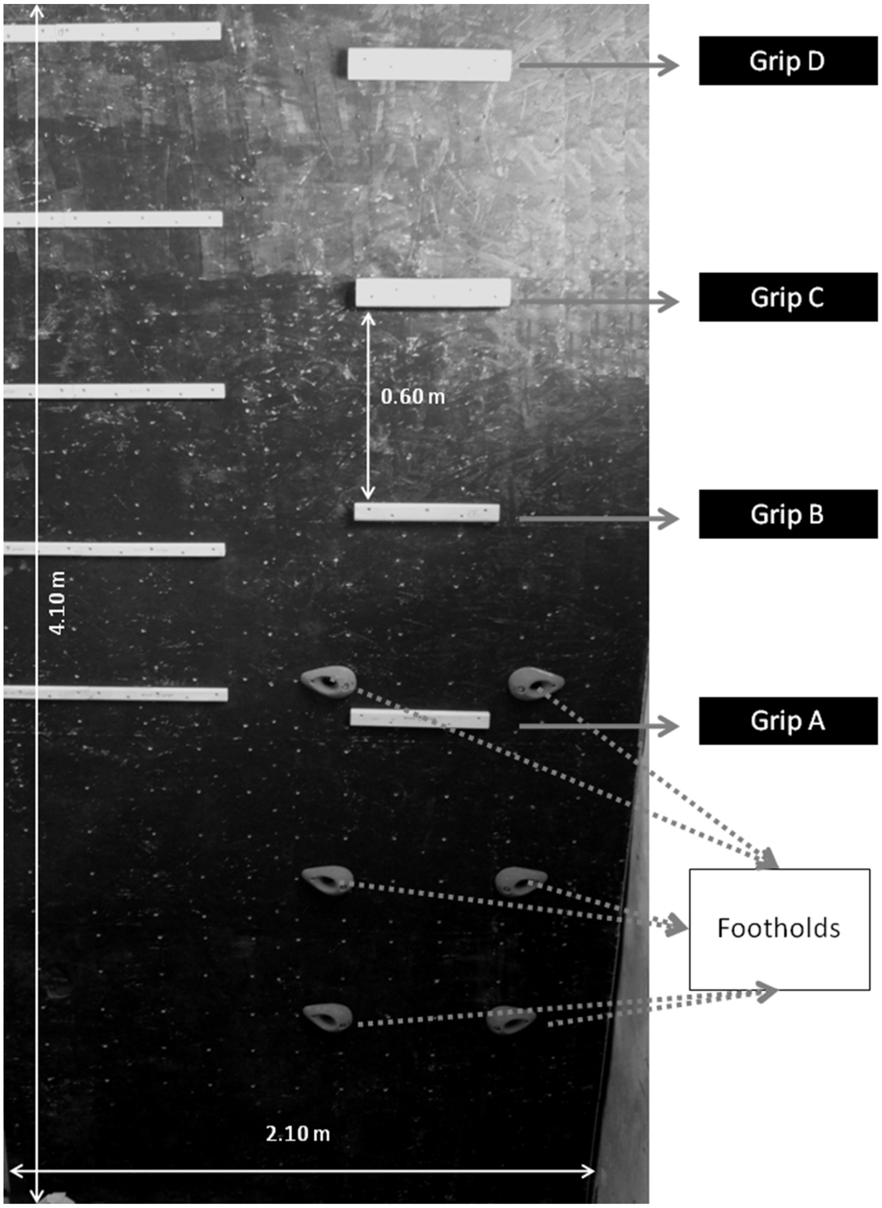
Figure 1. Intermittent isometric finger hang test (IFH) on the 30 mm deep crimp grip of the Alien fingerboard from the manufacturer Freestone (Saint Baldoph, FRA) fixed at 120° beyond vertical.

Figure 2. The 4.10 m high and 2.10 m wide bouldering wall set at 120° beyond vertical and equipped with four climbing grips and six footholds of 7 cm edge depth to assess climbing time to exhaustion.

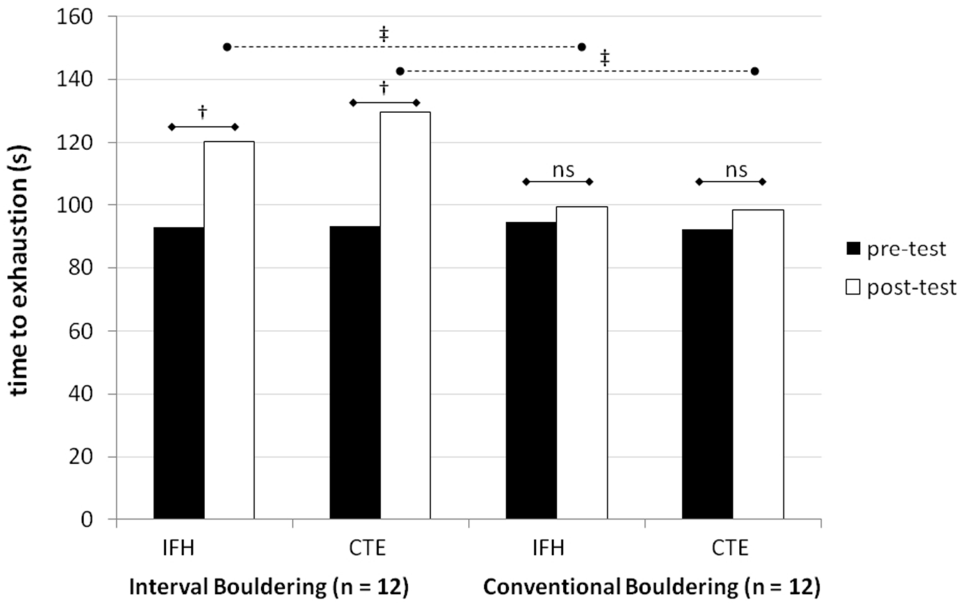
Figure 3. Hanging and climbing time to exhaustion in interval bouldering (IB) and conventional bouldering (CB) in pre- and post-test.



Intermittent isometric finger hang test (IFH) on the 30 mm deep crimp grip of the Alien fingerboard from the manufacturer Freestone (Saint Baldoph, FRA) fixed at 120° beyond vertical.
254x190mm (96 x 96 DPI)



The 4.10 m high and 2.10 m wide bouldering wall set at 120° beyond vertical and equipped with four climbing grips and six footholds of 7 cm edge depth to assess climbing time to exhaustion.
190x254mm (96 x 96 DPI)



Hanging and climbing time to exhaustion in interval bouldering (IB) and conventional bouldering (CB) in pre- and post-test.
254x190mm (96 x 96 DPI)