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Research article

Effects of Two vs. Four Weekly Campus Board Training Sessions on Bouldering Performance and Climbing-Specific Tests in Advanced and Elite Climbers

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Abstract
This study examined the effects of two or four weekly campus board training sessions among highly accomplished lead climbers. Sixteen advanced-to-elite climbers were randomly allocated to two (TG2), or four weekly campus board training sessions (TG4), or a control group (CG). All groups continued their normal climbing routines. Pre- and post-intervention measures included bouldering performance, maximal isometric pull-up strength using a shallow rung and a large hold (jug), and maximal reach and moves to failure. Rate of force development (RFD; absolute and 100ms) was calculated in the rung condition. TG4 improved maximal force in the jug condition (effect size (ES) = 0.40, p = 0.043), and absolute RFD more than CG (ES = 2.92, p = 0.025), whereas TG2 improved bouldering performance (ES = 2.59, p = 0.016) and maximal moves to failure on the campus board more than CG (ES = 1.65, p = 0.008). No differences between the training groups were found (p = 0.107–1.000). When merging the training groups, the training improved strength in the rung condition (ES = 0.87, p = 0.002), bouldering performance (ES = 2.37, p = 0.006), maximal reach (ES = 1.66, p = 0.006) and moves to failure (ES = 1.43, p = 0.040) more than CG. In conclusion, a five-week campus board training-block is sufficient for improving climbing-specific attributes among advanced-to-elite climbers. Sessions should be divided over four days to improve RFD or divided over two days to improve bouldering performance, compared to regular climbing training.

Key words: Isometric, pull-up, rate of force development, strength.

Introduction

Rock climbing has gained increased interest as both a recreational and competitive activity over the past decade, with an increasing amount of scientific literature focusing on performance-related factors of the sport. Although technical and mental factors certainly contribute to climbing outcomes (Baláš et al., 2014; Watts, 2004), it is widely accepted that strength and endurance of the upper-body is the primary predictor for climbing performance (Baláš et al., 2012; Mermier, 2000; Philippe et al., 2012; Quaine et al., 2003; Saul et al., 2019; Vigouroux and Quaine, 2006). Specifically, high levels of maximal and explosive strength of the fingers and forearms, elbow flexors, and shoulder- and back muscles (pulling apparatus) have been identified as significant attributes of highly accomplished climbers (Deyhle et al., 2015; Grant et al., 2001; Laffaye et al., 2014; 2016; Levernier and Laffaye, 2019b; Vigouroux et al., 2018).

A number of intervention studies have examined the effects of different resistance-training interventions on maximal and explosive upper-body strength among climbers (Hermans et al., 2017; Levernier and Laffaye, 2019a; López-Rivera and González-Badillo, 2012; 2019; Medernach et al., 2015; Philippe et al., 2019; Saeterbakken et al., 2018). Most of the existing literature has focused on specific, isolated finger flexor strength and endurance training (Levernier and Laffaye, 2019a; López-Rivera and González-Badillo, 2012; 2019; Medernach et al., 2015). Although improvement in climbing-specific tests have been reported after training interventions, most studies have neglected climbing performance as an outcome (Levernier and Laffaye, 2019a; López-Rivera and González-Badillo, 2012; 2019; Medernach et al., 2015). Further, finger strength has been measured using a handheld dynamometer (Medernach et al., 2015; Mermier, 2000) or during isometric hanging from shallow rungs with an external load (López-Rivera and González-Badillo, 2012), which do not mimic actual climbing where the pulling apparatus is used to produce vertical propulsion while the fingers are responsible for maintaining contact with the holds.

One method of climbing-specific strength training that has not received much scientific attention, but has been frequently used by highly accomplished climbers, is campus board training. Campus board training involves a series of upper-body moves on shallow rungs, without assistance from the feet. In addition to challenging the finger flexors, this training method involves dynamic, highly climbing-specific movements of the entire pulling apparatus. To the authors' knowledge, only one previous study has examined the effects of campus board training among climbers (Philippe et al., 2019). The authors reported similar improvements in on-sight lead climbing performance following hypertrophy- and endurance-focused training. Unfortunately, the researchers included several other training methods in the intervention (i.e., lead climbing, bouldering and pull-ups) and only tested performance through climbing, while neglecting measures of finger strength and endurance. Thus, the specific effects of the campus board training on finger strength and endurance remain unknown.

Some available evidence suggests that a higher number of weekly resistance training sessions might mediate gains in muscular strength and hypertrophy, possibly through more frequent elevations in muscle protein synthesis (Dankel et al., 2017). More frequent and shorter sessions could induce less fatigue and thereby allowing for

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greater adaptations, as maximal effort and velocity in the training is necessary for improving explosive strength (Behm and Sale, 1993; Sale and MacDougall, 1981). This could be of particular importance for campus board training, which is typically performed with maximal effort and highly explosive movements. Importantly, it has been suggested that dividing the training load over several shorter sessions might reduce the risk of overtraining and injuries (Hartman et al., 2007). This aspect has special relevance to campus board training, as this activity involves highly explosive movements placing extreme stress on the fingers, shoulders and elbows, which are the most frequent sites of injury among climbers (Grønhaug, 2018). Still, fewer and longer sessions could promote a higher tolerance to fatigue (Kraemer and Ratamess, 2005), which might benefit forearm endurance.

Despite a growing body of scientific literature examining climbing-specific resistance-training, the effects of training frequency have not yet been examined in relation to climbing, and many existing studies do not present actual climbing performance. Therefore, the aim of this study was to compare the effects of five weeks of campus board training performed either twice or four times per week on bouldering performance, upper-body pull-up strength (finger-, arm-, shoulder-, and back muscles) and campus board performance. We hypothesized that both training groups would improve their strength, rate of force development (RFD), bouldering performance and campus board performance (maximal reach and number of moves to failure) more than the control group. We expected that dividing the training volume over four days would improve bouldering performance, RFD and maximal reach more than two days, and that two weekly training sessions would produce the greatest gains in campus board moves to failure. The changes in maximal strength were expected to be similar between the training groups.

Methods

Participants

The inclusion criteria were a minimum self-reported red-point grade of 7a+ (IRCRA 18) and to have been free of climbing-related injuries in the last six months. Self-reporting grades have been shown to be highly reliable and acceptable for use in scientific contexts (Draper et al., 2011). Seventeen advanced-to-elite, amateur, male lead climbers volunteered for the study. Although a higher number of participants was desirable, the availability of high level climbers able to correctly perform the campus board training was limited. During the intervention, one participant from TG4 (IRCRA red-point = 23) acquired an injury unrelated to the study, leaving sixteen participants who finished all training and testing. Sample characteristics by group are presented in Table 1. The participants were familiar with the campus board but had not used it as a part of their training routine in the last six months. However, they were familiar with intense finger strength training (e.g., loaded fingerboard training) and experienced in subjectively monitoring the training load. After pre-testing, the participants were randomized to either a training group that trained twice per week (TG2; n = 6) or four times per week (TG4; n = 5), or to a control group (CG; n = 5). All groups were encouraged to continue their normal climbing and training routines, but the CG had to refrain from campus board and fingerboard training.

Experimental design

A randomized controlled trial was designed to investigate the effects of performing campus board training either two or four days per week for five weeks with equated volume. The pre-testing was divided over two days, separated by at least 48 - 72 hours. During the first visit, anthropometric variables, bouldering performance and maximal reach on the campus board were tested, in addition to a familiarization to the maximal force test using the rung hold. Finally, maximal isometric pull-up strength was tested in an isometric pull-up using the jug hold. During the second visit, maximal average force and RFD were collected from an isometric pull-up on a climbing-specific hold, followed by a number of moves to failure test on the campus board. The tests were performed in the order described above to avoid inter-subject variations in exhaustion. The participants were informed verbally and in writing about the potential risks and benefits of participation and signed and informed consent form before data collection began. The present research procedures were in accordance with the ethical guidelines of the university and conformed to the standards of treatment of human participants in research, outlined in the 5th Declaration of Helsinki. The preservation of the participants' safety and privacy was approved by the Norwegian Centre for Research Data (941687).

Table 1. Anthropometric variables, climbing experience, weekly climbing frequency and self-reported climbing ability for the three groups at baseline. Values are presented as means ± standard deviation.

	CG (n = 5)	TG2 (n = 6)	TG4 (n = 5)
Age (years)	30.6 ± 7.4	28.0 ± 5.8	32.6 ± 9.9
Height (m)	1.84 ± 0.08	1.80 ± 0.06	1.80 ± 0.06
Body mass (kg)	74.4 ± 4.7	73.7 ± 7.2	75.6 ± 2.7
Fat mass (%)	5.5 ± 2.4	7.5 ± 2.6	10.0 ± 4.7
Muscle mass (%)	89.7 ± 2.3	88.0 ± 2.5	85.5 ± 4.7
Experience (years)	10.0 ± 6.5	8.3 ± 2.4	8.6 ± 5.6
Weekly sessions (n)	3.6 ± 0.9	3.2 ± 0.8	3.4 ± 0.9
Best on-sight (IRCRA)	18.6 ± 3.2	18.2 ± 2.8	17.8 ± 2.9
Best red-point (IRCRA)	21.2 ± 3.3	21.3 ± 2.6	21.0 ± 2.7

On-sight and red-point grades are given using the grading system suggested by the International Rock Climbing Research Association (IRCRA) (Draper et al., 2016).

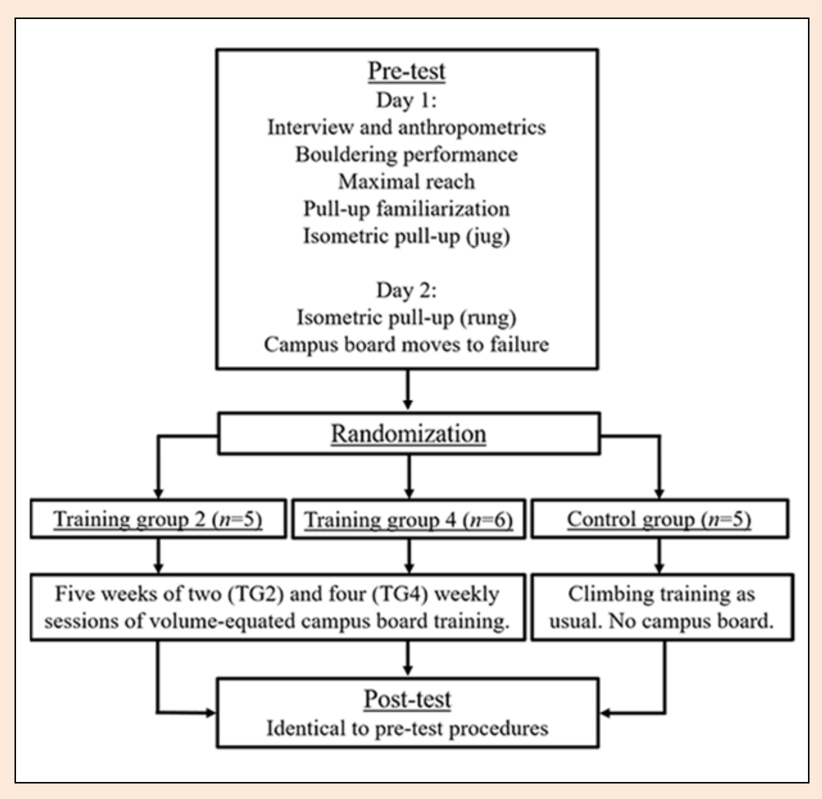

Figure 1. Flow-chart showing the study phases and the training intervention.

Procedures

An overview of the procedures (i.e., testing and training order) is presented in Figure 1. Upon initial visit to the laboratory, participants were interviewed about their climbing performance (best red-point and on-sight), climbing experience (consecutive years of regular climbing, defined as at least one weekly session on average), and number of weekly climbing sessions on average in the last two months. Weekly climbing sessions was collected again at post-test to detect any changes in training volume during the intervention. Thereafter, height was measured using a wall mounted measuring tape body mass, followed by fat mass and muscle mass measured using a bioelectric impedance scale (Tanita MC 780MA S, Tokyo, Japan). Finally forearm circumference was measured at 2/3rd the distance between the ulnar styloid process and the coronoid process using a measuring tape. Limb circumference has previously demonstrated good-to-excellent reliability (Bakar et al., 2017). The participants were then instructed to perform a 15- to 30-minute warm up in the bouldering wall using self-selected boulders and holds but maintain a low intensity and avoid fatigue.

Following the warm-up, bouldering performance was tested on two boulder problems that were suggested as grade 7A (IRCRA 20-21) by two independent, highly experienced route-setters. The two boulder problems consisted of five and ten moves using small holds (5 – 20 mm). Both were set on an artificial wall with an overhang of 25°. The order of the boulders was randomized and counter-balanced, but identical at pre- and post-test. The participants were given four minutes to work each boulder problem, and three minutes to rest between the two boulders. Participants could use as many attempts as they desired and the best attempt from each boulder was registered. The total number of completed moves (controlled contact with hold and attempting the next move) from the two boulder problems combined was used in the analyses (max score = 15). Three participants (one in each group) completed both problems on their first try and were therefore excluded from this analysis.

Approximately ten minutes after the boulder performance test, a maximal reach test was performed on the campus board with 20 mm deep and 60 cm wide rungs. The distance between rungs was 13 cm and the board had an overhang of 15°. Participants started with both hands on the lowest rung and were instructed to hang still before pulling themselves up and reaching as far as possible with a self-selected hand. Four attempts were given with at least one minute rest between the attempts. The highest rung they could reach and hang on to with one hand for two seconds was used in the analyses. The rung number was used as the unit of measurement.

Finally, participants were familiarized to the isometric pull-up on a 23 mm rung with rounded edges (Metolius Climbing, Bend, Oregon, USA), in which four-to-six trials were given, with feedback provided after each attempt. This rung size was chosen because it resembles the campus board rung size used in training (i.e., 15-25 mm). After being familiarized with the procedure, we measured the maximal isometric pull-up strength in a 90° elbow angle on the jug holds (depth: 30 mm, height: 30 mm, width: 70 mm) on a Beastmaker 1000 fingerboard (Beastmaker Limited, Leicester, United Kingdom) using the same protocol. A more extensive description of the pull-up test is provided below. Only one attempt was given in the jug condition as data from a pilot study showed a coefficient of variation (CV) of only 1.07% in this test. Participants were instructed to avoid performing strenuous climbing or climbing-related training in the 48 hours leading up to the second test-day.

The warm-up for the second day was identical as that for the first day. After the warm-up, the isometric pull-up was performed using a half crimp grip on the 23 mm deep rung (Metolius Climbing, Bend, Oregon, USA). A self-selected hand width was used, but the width had to be identical for all trials. The participants were anchored to the floor through a static system consisting of an expansion bolt in the concrete floor, a force cell with 200 Hz resolution (Ergotest Innovation A/S, Porsgrunn, Norway), a daisy chain, and a climbing harness (Figure 2) (Saeterbakken et al., 2020; Stien et al., 2019). The force output was registered using a computer with the commercial software MuscleLab (v. 10.4, Ergotest Innovation A/S, Porsgrunn, Norway). The harness was placed directly below the iliac crest and its position was controlled between attempts.

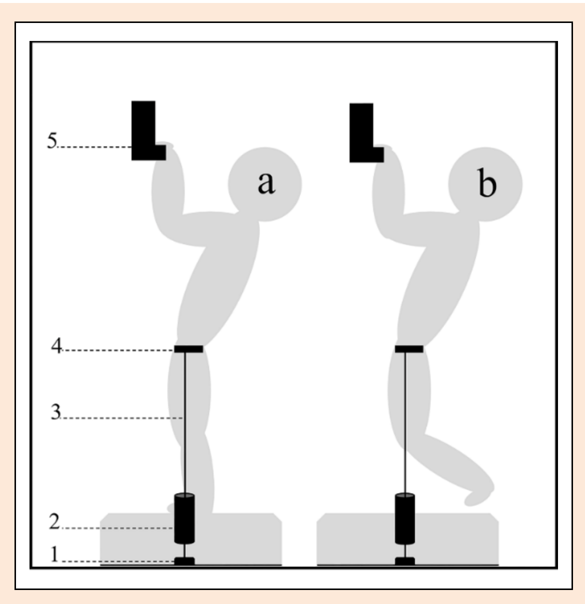

Figure 2. Schematic presentation of the test set-up during the isometric pull-up showing 1) expansion bolt in the concrete floor, 2) the force cell, 3) the static daisy chain, 4) the climbing harness, and 5) the 23 mm rung. The gray figure represents the climber before (a) and while (b) exerting maximal force. No horizontal or vertical displacement occurs between the two images.

Before performing the isometric pull-up, the participants stood on two step cases that were adjusted so that they could have their fingers on the rung and a 90° angle in their elbows (measured using a goniometer; Figure 2). The cases were used so that participants would not have to use arm muscle force to maintain the 90° angle before exerting maximal force. The participants were given real-time biofeedback of the force produced via a computer screen and had to maintain a steady baseline (no more than 4 N fluctuations in force) for one second before pulling. When a steady baseline was reached, the participants were instructed to pull as hard and as fast as possible for three-to-four seconds. These instructions were chosen to optimize both maximal force and RFD within the same attempt (Fanchini et al., 2013), in order to reduce the total number of attempts needed and to avoid excessive fatigue. For an attempt to be deemed acceptable, the following criteria had to be fulfilled: 1) no changes >4 N in baseline force before exerting maximal force, 2) continuous rise in force without a plateau before peak force output, and 3) no excessive peak force (> 20% of average force) as a result of creating momentum using hip flexion. Three acceptable attempts were required, and all participants were able to reach this within five attempts or less. A three-minute rest period was given between attempts.

All force curves were analyzed manually by the same researcher to avoid inter-subject variability. The absolute RFD (CV = 8.11%) was calculated as the change in force output from the onset of contraction to the maximal force output. The time used to reach maximal force was also registered to determine whether changes in RFD would be a result of increased maximal strength or decreased time to reach maximal force. Further, the RFD during the first 100ms from the onset (RFD_{100}; CV = 11.83%) was analyzed to examine the portion of RFD, which likely is more driven by neural factors rather than muscular properties (Levernier and Laffaye, 2019b). The onset was determined manually and identified as the point in time when the force rose by more than 4 N over the course of five milliseconds (Andersen and Aagaard, 2006; Levernier and Laffaye, 2019a; Levernier and Laffaye, 2019b). All force curves were enhanced (showing only a 100ms window) to accurately view the time of onset. The maximal average force was calculated as the highest average force across 1500ms (CV = 4.72%). The mean maximal force, RFD, and RFD_{100} across three attempts were used in the analyses.

Finally, we tested the maximal number of moves to failure on the campus board. For this test, participants started with both hands on the first rung and performed single moves until matching on the top rung before moving downward using the same pattern. Due to the fatigue of this test, only one attempt was given. For a move to be accepted as successful, the participants had to be in controlled contact with the hold and attempt to move to the next rung. The number of completed moves was registered and used in the analyses.

The exercises performed on the campus board were developed in cooperation with highly accomplished climbers who regularly used the campus board in their training. The campus board had three different depths of rungs (25, 20, and 15 mm) and participants were instructed to use the shallowest rung they could, and to progress to a shallower rung when possible. Each of the four exercises (see Table 2) was performed for a total of four sets within each session, leading with alternate hands. The TG2 performed all exercises twice per week over two days, whereas the TG4 performed two of the four exercises within each session, but trained four times per week and reached an identical volume as the TG2. The participants were instructed to rest for two-to-three minutes between sets, as regulated based on their perceived exhaustion. The duration of the training sessions, excluding the warm-up, were approximately 20 and 40 minutes for TG4 and TG2, respectively. All exercises were performed with maximal effort and velocity. The first training session was supervised to ensure correct execution of the exercises (e.g., not using a full crimp grip) and that the intensity (depth of rung) was high enough. All groups were instructed to continue their current climbing and training activity, but the CG was not allowed to commence campus board training during the intervention period. In week three, all participants were contacted to ensure that they were performing the prescribed sessions and did not experience an injury.

Statistical analysis

SPSS statistical software (Version 25.0, SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. Except for bouldering performance ($p = 0.001$), maximal reach ($P = 0.001$) and number of moves to failure ($p = 0.002$), the data material did not demonstrate deviations from normality (Shapiro-Wilk test; $p = 0.071 – 0.815$). Between-groups differences in the parametric variables were analyzed using an analysis of covariance (ANCOVA) with pre-test results as the covariate. When a significant main effect for group was found, Bonferroni post-hoc corrections were used to detect where the differences occurred. Between-groups differences in the non-parametric variables were analyzed using a Kruskal Wallis Test, followed by independent Mann-Whitney U-tests to detect the differences. Paired samples t-tests were used to determine if there were differences between the pre- and post-test results for the parametric variables, while a Wilcoxon signed rank test was used for the non-parametric variables. Statistical significance was accepted at $P \leq 0.05$. All data are presented as means ± standard deviation. For the within- and between-groups differences, Hedges' g effect size (ES) was calculated as the mean difference divided by the pooled and weighted standard deviations. The Hedges' d ES were interpreted as follows: < 0.2 = trivial; 0.2 – 0.5 = small; 0.5 – 0.8 = medium; > 0.8 = large (Cohen, 1988).

Table 2. The exercises performed throughout the intervention. The numbers represent the number of the rungs, with 1 being the lowest one on the board. All exercises started with both hands on rung number 1 and ended with both hands on the same top rung. The difference between rungs was 13 centimeters.

Order	Exercise	Description
1	1-4-7-10	Start with both hands on rung 1. Pull through each move and match hands on rung number 10.
2	Ladder	Keep one hand on the start rung and move the other hand up one rung at the time until max reach and reverse until the hands are matched on rung 1.
3	1-2-3	Move ca. 75% of max reach with one hand, then pull through as far as possible with the other hand. Follow with the first hand and match the top.
4	10 RM	Perform 10 consecutive moves of self-selected length so that the 10^{th} move is near exhaustion.

Note: The group that trained twice per week performed all the exercises within one session, while the group that trained four times per week alternated between exercises 1 and 2, and 3 and 4.

Results

Baseline results

Anthropometric variables, climbing frequency and self-reported climbing ability were not different between the groups at baseline ($F(2,13) = 0.018 – 2.242$, $P = 0.146 – 0.982$).

Training

The self-reported training attendance in TG2 and TG4 was 96.7% and 99.1, respectively. None of the three groups changed their number of weekly climbing sessions outside of the campus board training (average across groups: 3.6 ± 0.8 and 3.6 ± 0.9 at pre- and post-test, respectively) during the intervention ($p = 0.178 – 0.374$).

Performance outcomes

There was a difference between groups for the change in bouldering performance ($p = 0.024$). Bouldering performance improved in TG2 (ES = 0.25, $p = 0.042$), but not in TG4 ($p = 0.109$) or in the CG ($p = 0.157$). Further analyses revealed that TG2 improved bouldering performance more than the CG (ES = 2.01, $p = 0.016$). All groups improved the maximal number of moves to failure on the campus board (ES = 0.68 – 0.80, all $p = 0.043$), and TG2 increased number of moves more than the CG (ES = 0.87, $p = 0.008$). None of the groups significantly improved maximal reach ($p = 0.083 – 0.317$). No other differences between the three groups were found ($p = 0.095 – 0.556$; Table 3).

Pull-up force

The change in force output in the isometric pull-up performed on the 23mm rung demonstrated no differences between groups ($F(2,12) = 1.743$, $p = 0.217$). In the jug condition, a tendency for differences between groups at post-test was found ($F = 3.618$, $p = 0.059$). Post-hoc analyses revealed a tendency for greater improvement in force in TG2 compared to the CG (ES = 0.56, $p = 0.090$), while no other differences were found ($p = 0.140 – 1.000$; Figure 3).

Table 3. Results for maximal reach, maximal moves to failure, and bouldering performance with effect sizes (ES) for the pre-post change. Maximal reach is given as number of the rung reached, whereas moves to failure and bouldering performance are given as the total number of moves performed successfully before failure.

	Control group (n = 5)			2 weekly sessions (n = 6)			4 weekly sessions (n = 5)		
	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES
Max reach	7.6 ± 0.6	7.4 ± 0.6	0.33	7.3 ± 0.8	7.8 ± 0.8	0.63	7.2 ± 0.8	7.8 ± 1.1	0.63
Max moves	17.2 ± 5.6	23.2 ± 7.8*	0.90	28.8 ± 17.0	46.5 ± 23.7*	0.87	24.8 ± 23.8	42.0 ± 21.6*	0.76
Bouldering	10.1 ± 3.5	9.9 ± 3.5	0.06	9.8 ± 3.7	10.8 ± 3.4*	0.30	9.0 ± 3.5	9.7 ± 3.4	0.20

* = Significantly different from pre-test results ($p < 0.05$).

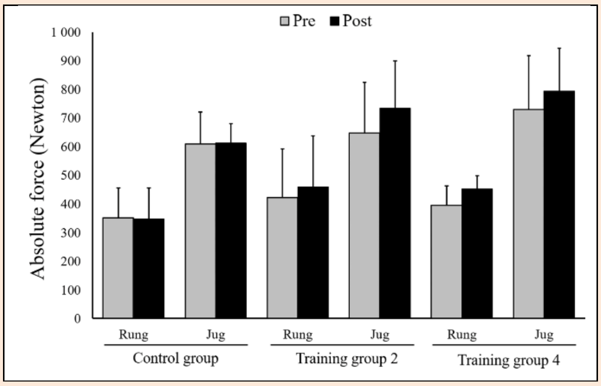

Figure 3. Pre- and post-test results for force output (Newton) in the rung and jug conditions.

Rate of force development

A difference in the change in RFD between groups was found (F(2,11) = 5.914, p = 0.018). No changes occurred in the CG (p = 0.160) or TG2 (p = 0.715), whereas RFD increased by 23.1 ± 3.1% in TG4 (ES = 0.57, p = 0.003). Post hoc analyses revealed that TG4 improved RFD more than the CG (ES = 1.68, p = 0.017), while no other differences were found between the groups (p = 0.256 – 268; Figure 4).

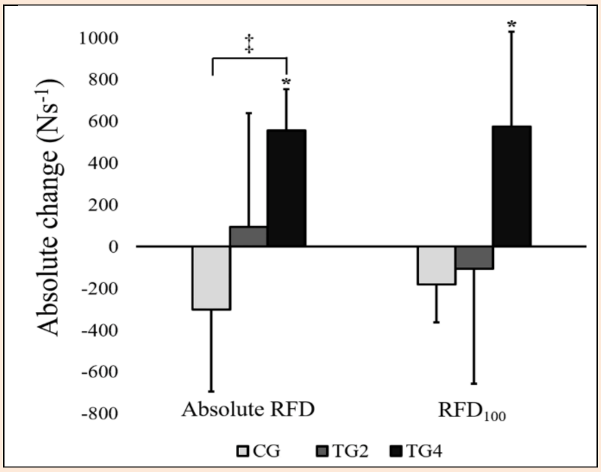

Figure 4. Absolute change in rate of force development (RFD (Ns^{-1})). Absolute RFD refers to the RFD calculated from the onset of force to the maximal force, while RFD_{100} refers to the RFD calculated as the rise in force in the first 100 milliseconds of contraction. * = significant change from pre-test (p < 0.05). ‡ = significant difference in change between groups (p < 0.05)

For RFD_{100}, a tendency was found for between-groups differences at post-test (F(2,11) = 3.679, p = 0.060). TG4 improved RFD_{100} by 29.6 ± 13.6% (ES = 0.37, p = 0.046), while the CG (p = 0.098) and TG2 did not (p = 0.689). Further analyses revealed no significant differences between groups (p = 0.095 – 1.000). The time (milliseconds (ms)) to reach maximal force did not demonstrate any differences between groups (F = 0.825, p = 0.464). The mean times to reach maximal force across all groups were 251.0 ± 75.6 ms and 261.9 ± 143.6 ms at pre- and post-test, respectively.

Arm circumference

The analyses revealed no significant between groups differences in the change in arm circumference (F(2,12) = 2.380, p = 0.135).

Training vs. Control

When merging the two training groups and comparing them to the CG, bouldering performance (ES = 1.42, p = 0.006), force in the jug condition (ES = 1.01, F(1,13) = 7.835, p = 0.015), absolute RFD (ES = 1.22, F(1,12) = 6.795, p = 0.023), maximal reach (ES = 1.51, p = 0.040) and number of moves to failure (ES = 0.85, p = 0.040) improved more in the training groups compared to the CG. Force in the rung condition (ES = 0.86, F(1,13) = 3.428, p = 0.087) and arm circumference (ES = 2.21, F(1,13) = 4.636, p = 0.051) demonstrated tendencies for a greater increase in the training groups. The change in RFD_{100} (F(1,12) = 0.918, p = 0.357) and time to reach peak force (F(1,12) = 2.402, p = 0.145) were not significantly different between groups.

Discussion

This study examined the effects of performing a five-week block of campus board training either two or four times per week with equated training volume. The main finding was that no differences occurred between the two training groups. However, only TG2 improved bouldering performance more than the control group, whereas only TG4 improved RFD more than the CG. When combining the training groups, the campus board training improved bouldering performance, maximal pull-up strength, RFD, maximal reach, and number of moves to failure more than the CG, while tendencies for greater improvements in arm circumference and rung strength were observed.

Although the change in RFD was not statistically different between the training groups, the ES for TG4 (ES = 0.63) was distinctly greater than for TG2 (ES = 0.12). Moreover, only TG4 improved RFD more than the active control group. By dividing the total training volume over several shorter sessions, it is possible that TG4 was able to maintain a higher effort and velocity throughout all sets compared to TG2 (i.e., higher campus board training quality), which has been shown to evoke greater improvements in RFD (Blazevich et al., 2020). The accumulated fatigue following a longer session could have reduced the ability of TG2 to maintain a high velocity throughout the session. Theoretically, the lack of difference between the training groups could be explained by the longer between-sessions rest for TG2, which could potentially have allowed for greater neural and muscular recovery and, thereby, been beneficial for the development of RFD (Rhea et al., 2003). It is possible that had we examined a longer training period and a higher number of climbers, four short sessions may have been proven significantly more effective for improving RFD. As no significant changes occurred in maximal pull-up force or the time to reach maximal force in the rung condition, the improved absolute RFD in TG4 was likely a result of neuromuscular adaptations in the early phase of the contraction. This speculation is supported by the fact that only TG4 improved RFD_{100}, which is more closely related to neural factors (e.g., motor unit discharge rate) than maximal strength (Maffiuletti et al., 2016). Of note, the available lab equipment dictated that the force sensor had to be anchored to the floor. A placement in direct contact with the fingers could possibly have provided a more sensitive measuring protocol for RFD.

Since previous investigations have identified high levels of RFD as an important attribute of boulder climbers (Fanchini et al., 2013; Stien et al., 2019), we expected the same group (TG4) to improve both RFD and bouldering performance. The difficult and steep boulder problems used for testing boulder performance were expected to require high levels of explosive strength (RFD), which only TG4 acquired to a greater extent than the CG. However, no difference between the training groups was found, and only TG2 demonstrated an improvement in bouldering performance that was greater than the CG. Importantly, a small ES for the improvement in bouldering performance was found for TG2 (ES = 0.30), which was only slightly larger than that observed for TG4 (ES = 0.21). It is possible that the maximal score of 15 moves did not provide a sufficiently sensitive test for detecting short-term improvements in bouldering performance. Still, the small effect and few participants are likely the main explanation for the lack of between-groups differences. This speculation is supported by the fact that increasing the statistical power (i.e., combining the training groups) demonstrated a distinctly greater improvement in the training groups compared to the CG. However, it is important to note that the study population comprised highly trained climbers, meaning that even a small improvement after only five weeks is practically meaningful.

As hypothesized, TG2 improved their number of moves to failure on the campus board more than the CG, while TG4 did not. The difference potentially occurred because the longer sessions performed by TG2 compared to TG4 produced a higher tolerance for fatigue (Kraemer and Ratamess, 2005), and thereby a more specific training stimulus toward this test. Specifically, the 10RM exercise (i.e., the exercise with the highest number of consecutive moves) was performed at the end of a longer session for TG2, meaning the moves were likely performed with a greater amount of fatigue than for TG4. Since the CG also improved in this test, one could speculate that familiarization to the campus board might be responsible for the improvement. Importantly, the CG continued their regular climbing training, which could explain the improvement for this group. Further, the improvement in all three groups were accompanied by quite large inter-individual variability. This could indicate that other factors, such as individual preference in technical execution of the test could have influenced the results more than forearm endurance. Thus, the findings from this test should be interpreted with caution. The same is true for the maximal reach performance, which is likely impacted by a combination of physiological, coordinative, and technical factors. This test is further limited by the distance between the rungs (13 cm) requiring large improvements for detecting potential changes. Moreover, although not measured in the present study, the campus board training might also have targeted attributes such as coordination and muscle synergy, which could impact bouldering performance. Therefore, it is problematic to directly link the findings from the lab test to the bouldering performance test.

Following the five-week training block, we were unable to detect differences in strength when analyzing the isometric pull-up on the 23mm rung and on the jug hold. The lack of differences between the two campus board training groups is likely a result of the identical volume between the groups, as evidence indicates training frequency does not influence strength gains under volume-equated conditions (Grgic et al., 2018). It could have been expected that the shorter exercise duration in TG4 would allow a higher intensity and effort, thus producing more prominent improvements in maximal strength of the fingers. However, given that all included participants had multiple years of climbing experience and performed at an advanced-to-elite level, the short-term training period was probably too short to achieve significant improvements in finger strength. Finally, it should be noted that the test set-up includes a complex task in which strength of both the fingers and shoulder girdle are challenged. While this probably allows for a highly climbing-specific task, it renders differentiation between the fingers and shoulders difficult. If possible, prospective studies should incorporate a measure of isolated finger- as well as shoulder girdle-strength to further elucidate which muscle groups are primarily impacted by campus board training.

The strength results from the present study may be difficult to compare with previous climbing interventions, where fingerboard training has been the most frequently examined resistance training method among climbers, with isolated testing of finger strength and endurance (Levernier and Laffaye, 2019a; López-Rivera and González-Badillo, 2012; 2019). Hence, changes in strength or RFD reported in these studies is reserved for the finger flexors. In line with the previous findings, when merging the two training groups the campus board training improved strength in the jug condition compared to the CG, with a tendency for a greater improvement in the rung condition. Hence, campus board training could be a viable option for improving climbing-specific strength. In contrast to the fingerboard (i.e., isometrically hanging from the fingertips), which is likely a more finger strength-specific exercise, campus board training can also improve maximal strength of the entire pulling apparatus in a climbing-specific task. Of note, performing climbing-related tasks (e.g., pull-ups) on small holds have been shown to reduce force production and impact the contraction strategies compared to larger holds (Stien et al., 2019; Vigouroux et al., 2018). Since the fingers are the weakest link in the pulling apparatus, potential training effects in the arms- and back muscles may not have been as clear using the rung test.

Although this study was, to the authors' knowledge, the first to examine the effects of campus board training frequency, some limitations should be considered when interpreting the results. The main limitation of this study was the low study sample size. One could speculate that the differences between groups would be more prominent with a greater statistical power. However, the aim of the study was to examine the effects among advanced and elite climbers and in order to increase the study population, less experienced climbers would have had to be included. Further, only male advanced and elite climbers were included in this study and the results may not be generalizable to females or climbers performing on other levels. Moreover, as only the first training session was supervised, the intensity was not monitored further during the intervention. However, the participants were experienced climbers and were familiar with performing high-intensity climbing-specific training (e.g., fingerboard), so we are confident that the protocol was carried out as directed. Importantly, the findings for bouldering performance are difficult to generalize as the routes and overhang differ between facilities. Future research examining bouldering performance should use equipment such as the Kilter board, allowing for identical routes to be compared across different locations. The effects of campus board training on speed- and lead-climbing performance should also be examined. Finally, the measuring method (i.e., isometric pull-up) could be considered unspecific to a dynamic training stimulus. Assessing power and velocity during a campus board-related task would likely have been more appropriate and should be considered in prospective studies. However, a non-specific exercise may provide additional information about isolated performance factors and the transferability of the training.

From a practical point of view, the findings of the present study suggest that campus board training can be an efficient training form that should be implemented in the training program of highly accomplished climbers. However, due to the great stress on the finger flexor muscles, it could be advisable to incorporate this training method in a block-periodized program. Emphasizing campus board training in a short block (e.g., five weeks) appears to be sufficient for improving several climbing-specific attributes regardless of training frequency. Importantly, no injuries occurred in the present study. Still, the authors suggest that climbers who are inexperienced to campus board approach the training method with a low training volume and moderate intensity and progress these variables as they gain more experience. Also, in a training block where campus board training is emphasized, climbers should consider reducing the volume of other climbing-related activities. Importantly, to the authors' knowledge, this is the first study to examine the specific effects of campus board training and future research should be conducted to confirm and expand on the findings.

Conclusion

In conclusion, the different training frequencies produced no significant differences between the training groups. However, among highly accomplished climbers, dividing the training volume over four shorter sessions improved RFD to a greater extent than the active control group, whereas performing two longer sessions improved bouldering performance and moves to failure on the campus board more than the active control group that continued climbing training as usual. Implementing campus board training, regardless of frequency, improved bouldering performance, RFD, maximal reach, number of moves to failure and arm circumference more than just climbing.

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Key points

- Five weeks of volume equated campus board training may similarly improve finger strength, maximal reach and number of campus moves to failure regardless of training frequency.
- Four weekly sessions may be more effective than two weekly sessions for improving rate of force development in an isometric pull-up using a climbing-specific hold
- Two weekly sessions could be more effective than four weekly sessions for improving bouldering performance when volume is equated.

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