Journal of Physical Activity Research, 2020, Vol. 5, No. 2, 79-84
Available online at http://pubs.sciepub.com/jpar/5/2/3
Published by Science and Education Publishing
DOI:10.12691/jpar-5-2-3

Eight Weeks of Supervised Indoor Climbing Significantly Reduces Arterial Pressure and Total Cholesterol in Recreational Climbers

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Received August 11, 2020; Revised September 14, 2020; Accepted September 23, 2020

Abstract The present study sought to investigate physiological adaptations associated with an 8-week supervised climbing intervention in recreational climbers. Nine participants (5 males and 4 females; age: 37 ± 8 years; stature: 169.7 ± 10.6 cm; body mass 83.3 ± 20.3 kg) volunteered to complete the intervention concomitant with their recreational climbing activities. Blood pressure, body composition, peak aerobic capacity, total cholesterol, and handgrip strength were assessed before and after the intervention. Post-intervention, diastolic blood pressure was significantly reduced (pre: 87 ± 6 mmHg, post: 72 ± 10 mmHg, p<0.01), without significant changes in systolic blood pressure (pre: 136 ± 15 mmHg, post: 128 ± 20 mmHg, p=0.19). This resulted in a significant reduction in mean arterial pressure (pre: 103 ± 9 mmHg, post: 90 ± 13 mmHg, p<0.01). A significant reduction in total cholesterol was also observed following the 8-week climbing intervention (pre: 5.09 ± 0.49 mmol/L, post: 4.39 ± 0.63 mmol/L, p<0.01). However, there were no significant changes in body fat percentage (p=0.67), skeletal muscle mass (p=0.76), isometric hand-grip strength (dominant hand: p=0.93, non-dominant hand: p=0.12) or peak aerobic capacity (p=0.37). Supervised indoor climbing exercise may therefore serve as an important non-pharmacological intervention to improve cardiovascular health by reducing mean arterial pressure and total cholesterol levels in recreational climbers, independent of changes in body composition or peak aerobic capacity.

Keywords: *cardiovascular, exercise, health, physical activity, climbing*

Cite This Article: Jane M. Black, Natasha Chenery, and Gavin Devereux, "Eight Weeks of Supervised Indoor Climbing Significantly Reduces Arterial Pressure and Total Cholesterol in Recreational Climbers." *Journal of Physical Activity Research*, vol. 5, no. 2 (2020): 79-84. doi: 10.12691/jpar-5-2-3.

1. Introduction

Indoor climbing, which comprises both vertical and horizontal movements on variable terrain fitted with artificial hand and foot holds [1], is becoming increasingly popular as a recreational activity. According to the International Federation of Sport Climbing (2020), up to 45 million people climb regularly, a number that will likely increase further following the inaugural inclusion of sport climbing in the 2021 Olympic Games. Despite the growing popularity of indoor climbing as a recreational sport, much of the climbing-based research to date has focussed on describing anthropometric and physiological characteristics of experienced climbers [2,3]. These include significant enhancements in vascular function, including higher peak vascular conductance and forearm vasodilatory capacity [4], as well as larger brachial artery diameters and greater capillary density [5]. Greater muscular strength and endurance [6] have also been demonstrated, although anthropometric differences between climbers and non-climbers remains equivocal [7].

Despite evidence of chronic adaptations associated with climbing exercise in experienced climbers, limited research has attempted to record the time course of adaptations to indoor climbing, instead reporting the physiological responses to a single ascent [3,8,9,10,11]. In contrast, Espana-Romero *et al.,* [1] investigated the physiological responses of experienced climbers to repeated ascents over a 10-week period, observing significant reductions in climbing time and absolute energy expenditure during climbing exercise. Given the superior physiological characteristics of experienced climbers reported in the literature, concomitant with the ever-increasing popularity of indoor climbing exercise amongst recreationally active individuals, it is pertinent to explore the health benefits of indoor climbing in recreational climbers. Therefore, the aim of this study was to investigate the physiological adaptations associated with an 8-week supervised climbing intervention in recreational climbers. It was hypothesised that 8-weeks of recreational climbing activity would lead to improvements in cardiovascular health, characterised by significant reductions in resting blood pressure, total cholesterol, and body fat percentage concomitant with significant increases in skeletal muscle mass and strength.

2. Methods

2.1. Experimental Design

To address the aims of this study, participants visited the Human Performance laboratory for the assessment of body composition, blood pressure, total cholesterol, handgrip strength and peak aerobic capacity on two separate occasions (pre and post intervention). All participants were asked to refrain from strenuous exercise, alcohol and caffeine for 24 hours prior to each visit. During the 8-week climbing intervention, participants took part in a weekly one-hour supervised indoor climbing session with an experienced coach, including the timed ascent of a standardised route. Participants were encouraged to continue with their normal timetable of unsupervised climbing sessions whilst enrolled in the study. The study protocol was approved by the School of Science, Technology and Engineering Research Ethics committee at the University of Suffolk and adhered to the Declaration of Helsinki.

2.2. Participants

Nine individuals (5 males and 4 females; age: 37 ± 8 years; stature: 169.7 ± 10.6 cm; body mass 83.3 ± 20.3 kg) volunteered to participate and provided written informed consent prior to testing. On enrolment to the study, all participants were members of an indoor climbing centre, but were not engaged in a formal training programme or competitive climbing. The current climbing experience of the sample ranged from 0-3 years, with a self-reported mean of 2 hours unsupervised climbing per week. Five of the participants reported a history of recreational climbing intermittently for many years prior to the study.

2.3. Experimental Procedures

2.3.1. Laboratory-based

Participants visited the Human Performance Laboratory on two separate occasions; once prior to, and once following the 8-week supervised climbing course. During each visit to the Human Performance Laboratory, body composition including body fat percentage (BF%) and skeletal muscle mass (SMM) was estimated using an 8-point bioelectrical impedance body composition analyser (mBCA 514, Seca, Hamburg, Germany), previously validated against magnetic resonance imaging [12]. Bilateral maximal handgrip strength was assessed using a dynamometer (TKK 5001 Grip-A Analog, Takei Scientific Instruments Co., Ltd, Japan). Total cholesterol (TC) concentration was measured using the reflectance measuring principle (Accutrend Plus, Roche Diagnostics GmbH, Mannheim, Germany); a capillary blood sample (15-40 µl) was collected from the middle finger of the non-dominant hand using an automated lancet device (Accuchek Softclix Pro, Roche Diagnostics GmbH, Mannheim, Germany) and transferred to the corresponding reagent strip for immediate analysis.

Resting brachial blood pressure was measured following 10 minutes of quiet, seated rest, using an automated sphygmomanometer in accordance with current guidelines published by the American College of Sports Medicine [13]. Systolic and diastolic blood pressures (SBP and DBP, respectively) were calculated as the average of three separate measurements. Mean arterial pressure (MAP) was calculated according to equation (1).

$$MAP = DBP + 1/3\,(SBP - DBP). \qquad (1)$$

Finally, all participants completed a maximal graded exercise test on a treadmill (Mercury Med, H/P/Cosmos, Sports & Medical GMBH, Germany) in accordance with published guidelines for the determination of peak aerobic capacity [13]. After 1 minute of standing, and a 3-minute warm up at 6 $km \cdot h^{-1}$, the test increased by 0.25 $km \cdot h^{-1}$ every 15 seconds until volitional fatigue. Ventilation and gas exchange data were recorded throughout the test using a breath-by-breath analysis system (Cortex Metalyzer, Cortex Biophysik GmbH, Leipzig, Germany) which was calibrated according to the manufacturer's instructions prior to each test. Heart rate (HR) was also recorded continuously throughout the protocol (T31, Polar Electro Ltd, Kempele, Finland).

2.3.2. Climbing-based

The 8-week climbing intervention was designed and delivered by qualified instructors with the objective of improving climbing proficiency through weekly 60-minute technique masterclasses including footwork, grip methods, balance and conditioning. Weekly, each participant also completed a timed ascent, using one route of a tri-graded circuit board designed by an experienced route setter. The difficulty of the specific route was rated as 5A on the French Grading System and contained 31 holds bolted to the surface of the climbing wall, which could be used by the participants for both hand and foot support. Participants were required to progress along the holds in numerical order and climbing time was recorded from the point of initial hand contact with the first hold, to loss of contact with the climbing wall.

2.4. Statistical Analysis

A priori power analysis was used to estimate sample sizes based on previously published data [8]. To achieve 80% power to detect the same changes in climbing time, with alpha equal to 0.05, the present study required 6 participants. Prior to analysis, data were examined for the assumption of normality using a Shapiro-Wilk test. A paired samples T-test was used to detect differences between pre and post data, for all variables. Effect sizes (ES) were calculated using Cohen's d and are reported in conjunction with 95% confidence intervals (95%CI) of the difference between pre and post measures, for all analysed variables. For all statistical analysis, SPSS (version 19.0, Chicago, IL) was used, with alpha set at 0.05.

3. Results

As expected, duration of the pre-determined circuit board climb reduced significantly following the 8-week intervention (pre: 88 ± 36 seconds, post: 64 ± 26 seconds, p=0.01; ES = 1.12; 95%CI: 7.38, 43.11). Results of the statistical analysis revealed that following 8-weeks of supervised indoor climbing exercise, diastolic blood pressure was significantly reduced (pre: 87 ± 6 mmHg; post: 72 ± 10 mmHg; p<0.01; ES=2.01; 95%CI: 9.73, 21.83). Similarly, mean arterial pressure was also significantly reduced (pre: 103 ± 9 mmHg; post: 90 ± 13 mmHg; p<0.01; ES=1.46; 95%CI: 6.07, 19.86). These changes were observed without any significant changes in systolic blood pressure (pre: 136 ± 15 mmHg; post: 128 ± 20 mmHg; p=0.19; ES=0.48; 95%CI: -4.44, 19.11, Figure 1).

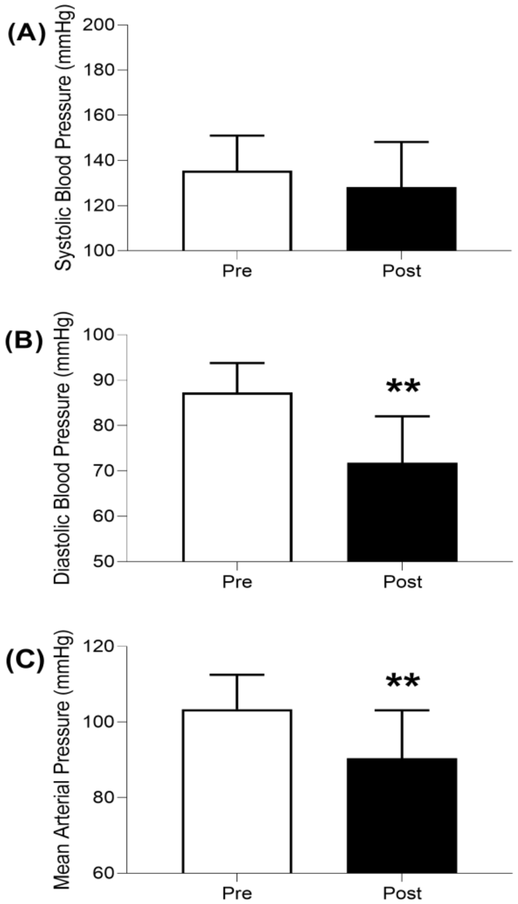

Figure 1. (A) Systolic, (B) Diastolic and (C) Mean arterial blood pressures pre *(white bars*) and post *(black bars)* intervention. ** Significantly different from pre-intervention measurement; p<0.01. Values are means ± SD.

A significant reduction in total cholesterol was also observed following the 8-week climbing intervention (pre: 5.90 ± 0.49 mmol/L; post: 4.39 ± 0.63 mmol/L; p<0.01; ES=1.89; 95%CI: 0.39, 1.00, Figure 2).

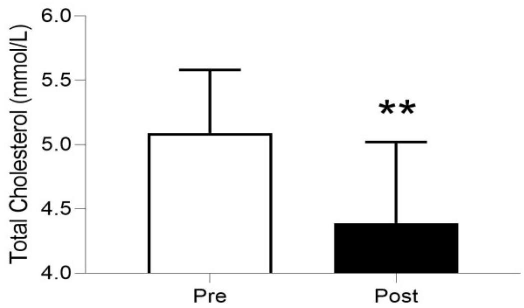

Figure 2. Total cholesterol pre *(white bars)* and post *(black bars)* intervention. ** Significantly different from pre-intervention measurement; p<0.01. Values are means ± SD.

There were no significant changes in body composition (body fat percentage and skeletal muscle mass), isometric hand-grip strength, resting HR or peak aerobic capacity (all p>0.05, Table 1).

Table 1. Physiological parameters before and after the 8-week climbing intervention

	Pre	Post	P-Value	ES	95% CI of the difference
BMI (kg/m^2)	29 (±7)	29 (±7)	*0.91*	*0.02*	*-0.40, 0.44*
BF (%)	27 (±12)	26 (±12)	*0.67*	*0.59*	*-0.09, 2.14*
SMM (kg)	29 (±7)	29 (±7)	*0.76*	*0.11*	*-0.91, 0.69*
Peak Aerobic Capacity (ml.kg.min^{-1})	32 (±8)	32 (±8)	*0.37*	*0.17*	*-0.36, 0.76*
RHR (bpm)	76 (±17)	74 (±8)	*0.51*	*0.23*	*-8.73, 16.29*
Dominant RHG (kg)	35 (± 10)	35 (± 13)	*0.93*	*0.03*	*-4.84, 4.49*
Non-dominant RHG (kg)	37 (± 11)	40 (± 14)	*0.12*	*0.57*	*-7.92, 1.09*

BMI: body mass index; BF: body fat; SMM: skeletal muscle mass; RHR: resting heart rate; RHG: resting handgrip; ES: effect size (Cohen's d). Values are presented as means (± SD).

4. Discussion

The aim of this study was to investigate the physiological adaptations associated with an 8-week supervised climbing intervention in recreational climbers. It was hypothesised that 8-weeks of supervised climbing activity would lead to significant reductions in resting blood pressure, total cholesterol, and body fat percentage concomitant with significant increases in skeletal muscle mass and strength. The main findings of this study suggest that 8-weeks of supervised indoor climbing elicit significant improvements in climbing speed, and significant reductions in resting DBP, MAP and total cholesterol levels. There were no significant changes in SBP, body composition (body fat percentage and skeletal muscle mass), isometric hand-grip strength or peak aerobic capacity.

Indoor climbing exercise provides a physiologically unique stimulus characterised by repeated intermittent isometric contractions of the forearm musculature [10]. Whilst resistance training is rarely prescribed to enhance cardiovascular health, some evidence supports isometric exercise as a more effective stimulus for eliciting reductions in blood pressure compared with dynamic aerobic and resistance exercise [14]. Isometric exercise has also been suggested as an effective modality to reduce arterial pressure at rest, but not during exercise [15]. Although blood pressure was not assessed during exercise, results of the present study provide further support that climbing exercise can significantly reduce resting mean arterial pressure via reductions in diastolic, but not systolic blood pressure. Previous studies have also demonstrated reductions in DBP but not SBP using isometric exercise in younger, older, and borderline hypertensive populations [15].

The significant reductions in DBP observed in the present study are unlikely to have occurred as a result of central haemodynamic changes, as neither SBP (p=0.19) or HR (p=0.51) were altered [15]. Furthermore, previous research investigating the effects of isometric exercise on decreases in DBP have reported no change in resting muscle sympathetic nerve activity (MSNA), suggesting that the changes observed are not related to a reduction in sympathetic outflow [15]. Collectively, these findings may suggest that peripheral vascular changes are responsible for the reductions in diastolic blood pressure observed in the present study. During climbing-based exercise, whilst it is difficult to estimate the exact percentage of maximal voluntary contraction utilised, the forearm musculature and vasculature is likely placed under repeated periods of ischemia [16]. Consequently, climbing exercise may provoke repetitive increases in shear stress, leading chronically to an upregulation in the release of endothelium-derived nitric oxide and consequently, to vascular remodelling [17]. In support, low-load isometric hand-grip exercise with blood flow restriction has been associated with significant increases in brachial artery diameter following just 4-weeks of training [18]. Thompson *et al.*, [5] have also reported significantly greater peak reactive hyperaemic blood flow and capillary filtration capacity in regular climbers (with a minimum of 3-years climbing experience) compared to controls. The climbers also demonstrated significantly greater resting, peak and maximal brachial diameters, but no significant difference in flow-mediated dilation or resting blood pressure compared to the control group [5]. This might suggest that the significant reductions in DBP observed in the present study are more readily observed in individuals with an elevated blood pressure or stage one hypertension, as per the American Heart Association Guidelines [19]. Previously, a 5-6 mmHg reduction in DBP has been reported to decrease coronary heart disease incidents by 16% and stroke incidents by 38% [20]. As such, interventions suitable for the primary prevention of cardiovascular disease are considered highly desirable. Results of the present study suggest that increased participation in recreational climbing exercise may enhance the prospect of positive clinical outcomes in individuals with elevated blood pressure. As such, a short-term supervised climbing intervention may have a meaningful impact in the prevention of cardiovascular disease and promotion of cardiovascular health, although further research is still required. Future studies should try to understand the mechanisms responsible for the reductions in DBP observed, by documenting the time-course of any changes in vascular structure and function associated with indoor climbing exercise.

Individuals with elevated cholesterol levels (>5.17 mmol/L) have a reportedly doubled risk for coronary heart disease compared to those with optimal levels (<4.66 mmol/L) [21]. The significant reduction in total cholesterol observed in the present study was associated with a shift from elevated (5.1 mmol/L) to optimal (4.4 mmol/L) levels. Previous review papers have reported the beneficial effects of exercise on lipid profiles [22], including the suggestion that a dose-response relationship may exist between physical activity and improvements in the lipid profile [23]. The results of the present study suggest that the introduction of a 60-minute supervised indoor climbing session, in addition to approximately 120 minutes of unsupervised recreational climbing per week, is sufficient to observe significant reductions in total cholesterol concentration after 8 weeks. These findings are in agreement with the study by Fett *et al.*, [24] who also reported significant reductions in total cholesterol following 8-weeks of resistance training for similar durations, but without specific intensities. These findings emphasise the importance of training volume over training intensity for promoting improvements in the lipid profile, and consequently, may explain why significant reductions in total cholesterol were observed concomitant with the addition of a 'supervised' session to the participants' climbing regime.

The exact mechanisms for the improvements in total cholesterol associated with isometric exercise remain elusive, however, it has been postulated that physical activity-induced increases in high-density lipoprotein function may serve as an underlying factor [25]. Consequently, the measurement of total cholesterol is a limitation of the present study, and future studies should seek to profile specific changes in high-density lipoprotein, low-density lipoprotein and triglyceride levels associated with recreational climbing.

In the present study, eight weeks of supervised indoor climbing exercise did not lead to changes in body composition (assessed via body fat percentage and skeletal muscle mass) or hand-grip strength. Previous research investigating the effects of indoor climbing on these variables is equivocal, with cross-sectional studies reporting no differences in body composition [6], or handgrip strength [5,6] between climbers and non-climbers. A seven-week intervention, prescribing 4-hours of climbing per week, also reported no significant changes in body composition measures (body fat percentage, body mass, body mass index or sum of skinfolds) in recreational climbers, but a significant 6.5% increase in dominant and non-dominant handgrip strength was observed [26]. In the present study, increases in handgrip strength of 8.1% were noted in the non-dominant hand (with no increases in dominant handgrip strength), however the results were not statistically significant, potentially due to the smaller sample size. Although not significant, the observation of a greater increase in mean handgrip strength of the non-dominant hand is expected, likely due to the non-discriminatory use of both hands during climbing exercise [27].

More recently, Li *et al.*, [28] sought to assimilate all available data relating to the effect of indoor rock climbing on body fat percentage, handgrip strength and peak aerobic capacity in recreational climbers. In accordance with the findings of the present study, a meta-analysis of 81 participants revealed no significant effect of indoor climbing on body fat percentage. In contrast, meta-analysis of 118 participants revealed significant increases in combined dominant and non-dominant handgrip strength. Recreational climbing exercise was also associated with a significant increase in peak aerobic capacity, which is in contrast to the findings of the present study. Only two studies were included in the meta-analysis for peak aerobic capacity, highlighting the paucity of available data. One of the two studies used a 24-week intervention, and the other prescribed 180 minutes of climbing per week at 70% of heart rate reserve

[29]. Consequently, these studies provide evidence that indoor climbing can lead to significant increases in peak aerobic capacity amongst recreational climbers, and further suggest that the duration and intensity of the intervention used in the present study may have been insufficient to result in physiological adaptations. However, as high aerobic power is not a determining factor of performance for indoor climbing [27], it remains an accessible mode of exercise for sedentary and recreationally active individuals. Collectively, the findings of the present study indicate that a supervised indoor climbing intervention can lower risk factors for cardiovascular disease amongst recreationally active individuals, independent of changes in peak aerobic capacity or body composition.

In addition to limitations already mentioned, we were unable to measure indices of arterial structure and function during this study and are therefore unable to draw firm conclusions about the mechanisms responsible for the reductions in DBP observed. In the future, the addition of measurements such as arterial diameter and flow mediated dilation would be informative in developing a greater understanding of the cardiovascular adaptations to indoor climbing. Furthermore, the heterogeneity of the sample may be considered a limitation by some, however the physiological responses to climbing are not thought to be influenced by sex differences [9,30], and as with previous research in this area [27], use of broad inclusion criteria ensures that results are applicable to the general adult population.

5. Conclusion

Supervised indoor climbing exercise may serve as an important non-pharmacological intervention to improve cardiovascular health by reducing mean arterial pressure and total cholesterol levels in recreational climbers. The findings of the present study indicate that indoor climbing can lower risk factors for cardiovascular disease independent of changes in peak aerobic capacity, body mass, or body composition. Future studies should try to understand the mechanisms responsible for the reductions in arterial blood pressure observed, via detailed assessment of changes in arterial structure and function associated with indoor climbing.

Acknowledgements

The authors would like to thank Avid Indoor Climbing Ltd, for their collaboration in this project, and their assistance with data collection.

Abbreviations

BF%: Body Fat Percentage
BMI: Body Mass Index
DBP: Diastolic Blood Pressure
HR: Heart Rate
MAP: Mean Arterial Pressure
MSNA: Muscle Sympathetic Nerve Activity
RHG: Resting Handgrip
RHR: Resting Heart Rate
SBP: Systolic Blood Pressure
SMM: Skeletal Muscle Mass
TC: Total Cholesterol

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