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Effects of High and Low Intensity Endurance Training With and Without Blood Flow Restriction on 3-km Running Performance

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ABSTRACT

We investigated the effects of high- and low-intensity endurance training, with and without blood flow restriction (BFR), on 3-km running performance in recreational athletes. Thirty-one recreationally trained runners (18 men and 13 women, age: 39 ± 5.2 years, height: 171 ± 7 cm, body mass: 71 ± 11 kg) were divided into 4 groups: low-intensity group (LI) and low-intensity group with BFR (LI+BFR) who completed 3 km at 60% vVO_{2peak}; high-intensity group (HI) and high-intensity group + BFR (HI+BFR) who completed 10 × 300 m at 90% vVO_{2peak} with 90 s of recovery. Participants performed the experimental protocols twice a week for 4 weeks in addition to their regular training. Before and after the 4-week intervention, participants completed a 3-km and an incremental test on the treadmill. LI + BFR, HI, and HI + BFR improved 3-km performance, while LI had not effect. Changes in LI + BFR and HI + BFR were greater than those observed in LI. BFR added to endurance training may help improving performance in recreationally trained runners with specific adaptations depending on the intensity used.

Keywords: exercise, performance, endurance training, running

INTRODUCTION

Middle- and long-distance running training consists of performing both continuous and interval training sessions at intensities ranging from low- to high-intensities (1). Continuous training consists of performing the training bout for an extended period without pause at low-moderate intensities. Interval training is performed with bouts of high-intensity interspersed with periods of active or passive recovery, thus allowing the completion of higher volumes at intensities above the anaerobic threshold or critical velocity (2).

Previous literature has investigated the effects of manipulating intensity, volume, recovery between efforts and frequency of training to optimize endurance performance (3). These studies have suggested that 70-80% of training volume should be carried out at intensities around the first metabolic threshold, while the remaining volume is completed at the moderate and high-intensity training zones(4, 5).

The combination of high volume at low-to-moderate intensities and high-intensity training sessions plays an important role in improving endurance performance. However, increasing training volume or intensity is not an easy endeavour. Training volume has been associated with an increased injury risk (6), whereas frequent high-intensity training has been associated with greater risk of overreaching and overtraining (7, 8).

One alternative to lower the external load during running training is the use of blood flow restriction (BFR). BFR, which consists of wrapping a cuff or an elastic band to the proximal region of upper or lower limbs during exercise, has recently revealed promising results for runners when associated to both high- and low-intensity training. Previously, Abe et al. (9) demonstrated that low-intensity (40% of VO_{2max}) training with BFR in a cycle ergometer induced significant improvements in VO_{2max} (6.4%) and exercise time until exhaustion (15.4%). Subsequently, Keramidas et al. (10) reported an increase in peak power output after 6 weeks of high-intensity training with BFR when compared with a control group. Similarly, Park et al. (11) observed an increased ejection volume, anaerobic capacity and maximal oxygen consumption (VO_{2max}) after a 2-week walking with BFR. However, none of these studies investigated the effects of BFR associated with low- vs. high-intensity training on endurance performance. This comparison would allow to select the more efficient combinations of low- and high-intensity bouts depending on the additive effects of BFR to running.

Thus, the objective of this study was to compare the effects of endurance training performed at both low- and high-intensity with and without BFR on running performance. We hypothesized that BFR would augment running performances in recreationally trained runners when compared to the training regimens without BFR.

METHODS

Participants

Forty-four recreational runners with a self-reported 10-km performance <50 minutes for men and <55 minutes for women, volunteered for participation in this study. We chose this performance difference between sexes because men are, on average, ~11% faster than women in athletic running events. Thirteen participants did not complete all the procedures due to personal reasons unrelated to the study, and their data were excluded from the analysis. Thus, data for the remaining 31 participants were subsequently analyzed. Participants were initially classified into quartiles according to baseline 3-km performances, and then within each quartile they were randomly assigned to one of the four experimental groups: low-intensity continuous training (LI , n = 7, age: 39 ± 6 years, height: 171 ± 7 cm, body mass: 69 ± 8 kg, VO_{2peak}: 50 ± 5 $mL \cdot kg^{-1} \cdot min^{-1}$); low-intensity continuous training + BFR (LI+BFR , n = 8, age: 38 ± 5 years, height 169 ± 7 cm, body mass: 67 ± 7 kg, VO_{2peak}: 51 ± 10 $mL \cdot kg^{-1} \cdot min^{-1}$); high-intensity interval training (HI, n = 7, age: 37 ± 5 years, height: 170 ± 8 cm, body mass: 67 ± 12 kg, VO_{2peak}: 54 ± 11 $mL \cdot kg^{-1} \cdot min^{-1}$); and high-intensity interval training + BFR (HI+BFR, n = 9, age: 40 ± 5 years, height: 173 ± 6 cm, body mass: 78 ± 13 kg, VO_{2peak}: 51 ± 6 $mL \cdot kg^{-1} \cdot min^{-1}$). Due to the nature of interventions, participant blinding was not possible. However, to minimize bias, the researcher responsible for testing participants was blinded to the group allocation. All of them were free from any injury or illness that may interfere on the study procedures. All participants were instructed to avoid the consumption of alcohol, tobacco, and caffeine 24-h prior to evaluations, and not to perform strenuous exercise 48-h prior to the physical tests. All participants were informed about the procedures, benefits, discomforts, and possible risks of the study and signed an informed written consent form before participation. The local University Ethics Committee approved the experimental procedures (approval number 2.791.260). We asked participants to keep their training routine stable, without major increases or decreases in volume or intensity.

Procedures

Before the training intervention, participants performed 3 testing sessions with 48 hours between them. In the first session, participants completed a 3-km time-trial (TT) on an outdoor track (400 m) to determine on field endurance running performance. During the second testing session, they performed a maximal incremental test on a treadmill to determine peak oxygen consumption (VO_{2peak}) and peak velocity (PV). The third session was designed to familiarize participants with BFR and to adjust elastic knee wraps around the proximal site of their thighs to ensure a subjective feeling around 6-7 out of 10 (12, 13). Subsequently, they performed a 2-km continuous running at 60% of vVO_{2peak} and 5 × 300 m at 90% of vVO_{2peak} with 90 s of active recovery after 5 min of recovery between running bouts. We selected elastic bands as it is a more feasible method to be used in the field (13), thus increasing the ecological validity of the study. After the training intervention, participants only performed the 3-km time-trial (TT).

The experimental training sessions were performed twice a week during four weeks with, at least, 48 hours between sessions. Briefly, after the warm-up, the low intensity training groups continuously performed 3,000 m at 60% of their PV, while the high-intensity groups performed 10 × 300 m at 90% of their PV. Participants of the BFR groups adjusted the elastic knee wraps around the proximal portion of their thighs as explained in the familiarization sessions and were required to maintain the BFR during the entire training session. All participants were oriented to continue their regular training routines the other days of the week during the 4-week experimental training period (LI – 27.6 ± 4.0 km, 50.2 ± 4.5 ml $O_2.kg^{-1}.min^{-1}$, LI+BFR – 26.5 ± 2.6 km, 51.1 ± 9.7 ml $O_2.kg^{-1}.min^{-1}$, HI – 26.7 ± 2.6 km, 53.6 ± 12.1 ml $O_2.kg^{-1}.min^{-1}$, HI+BFR – 28.0 ± 1.9 km, 50.8 ± 6.4 ml $O_2.kg^{-1}.min^{-1}$).

Performance test

Running performance testing consisted of a 3-km run in a 400-m outdoor track. Participants performed a 2-km warm-up at a self-selected (submaximal) intensity. The 3-km running test started after 10 minutes of rest. Participants ran alone in the track and were allowed to freely choose their pacing strategy and were also instructed to complete the distance as fast as possible. Pre- and post-tests were performed at the same time of day ± 1h to avoid the influence of circadian rhythms on performance.

Blood flow restriction

Blood flow restriction (BFR) was subjectively applied by every participant with a 20-cm elastic band placed proximally on each lower limb which was maintained throughout the experimental sessions, including recovery periods (13).

Statistical analysis

All data analysis were run on JAMOVI software v. 2.3.28. Data normality was checked with Shapiro-Wilk test. Data for 3-km performance are presented as mean and standard deviation and were analyzed using ANCOVA having groups as fixed factor and pre-values as covariate. Prior to conducting the ANCOVA, we tested the assumption of homogeneity of regression slopes by including the interaction term between the pre-test scores (covariate) and group in the model. The interaction was not statistically significant ($F(3, 23) = 0.37$, $p = 0.778$), indicating that the relationship between the covariate and the post-test scores did not differ significantly across groups. Therefore, the assumption was met and the ANCOVA was deemed appropriate. Pre-to-post changes were considered significant when 95% confidence interval of the estimated marginal means did not contain zero. Baseline VO_{2max} was compared using a one-way ANOVA. When a significant F value was observed, Tukey's post hoc was used for pairwise comparisons. Pearson product moment correlation coefficient (r) was used to investigate the association between baseline performance level and changes in performance. The level of significance was set at p <0.05. Between-group Cohen's d effect size was calculated based on the estimated marginal means.

RESULTS

Figure 1 displays pre- and post- data for the 3-km performance. Decreases in the 3-km completion time were observed in all training groups except LI (3.45 [-5.8, 12.7 s]). Participants in LI + BFR, HI, and HI + BFR showed substantial decreases in performance time (LI + BFR = -26.3 s [-34.9, -17.7 s]; HI = -12.1 s [-21.4, -2.8 s]; HI + BFR = -20.0 s [-28.4, -11.7 s]). Changes in LI + BFR and HI + BFR were greater than those observed in LI (29.7 s [12.8, 46.7 s], p<0.001, ES = 2.52; 23.5 s [6.5, 40.5 s], p=0.004, ES=1.99, respectively), while changes in HI and HI + BFR were similar (7.9 s [9.1, 24.9 s], p = 0.589, ES = 0.67).

DISCUSSION

The aim of the study was to compare the effects of a 4-week endurance training intervention at low- and high-intensity with and without BFR on 3-km time trial performance. The results indicate that changes induced by training associated with BFR, regardless of intensity, were greater than changes induced by low-intensity training.

Although, low-intensity endurance training is commonly performed by world-class endurance athletes, and the volume of low-intensity training is related to running performance (14), the specific LI protocol used in this study, performed twice a week in addition to regular training was less effective than both BFR conditions and HI in promoting short-term improvements in 3-km performance. Considering that athletes are adapted to low-intensity training, it is tempting to suggest the LI did not improve due to the low-volume or to the short period of the

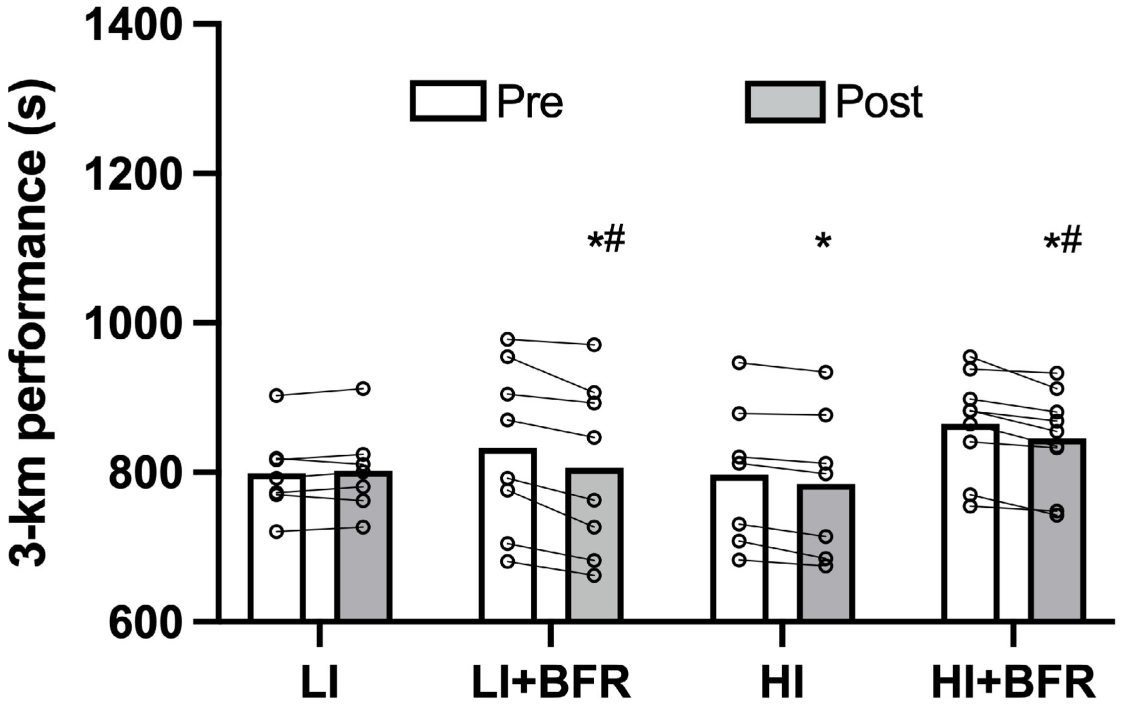

Figure 1. 3-km performance (s) (mean and individual values) in the four training groups. LI – low intensity, LI + BFR – low intensity + BFR, HI – high intensity and HI + BFR – high in-tensity + BFR. * - $p<0.05$ compared to the pre-value, # - $p<0.05$ between-group comparison

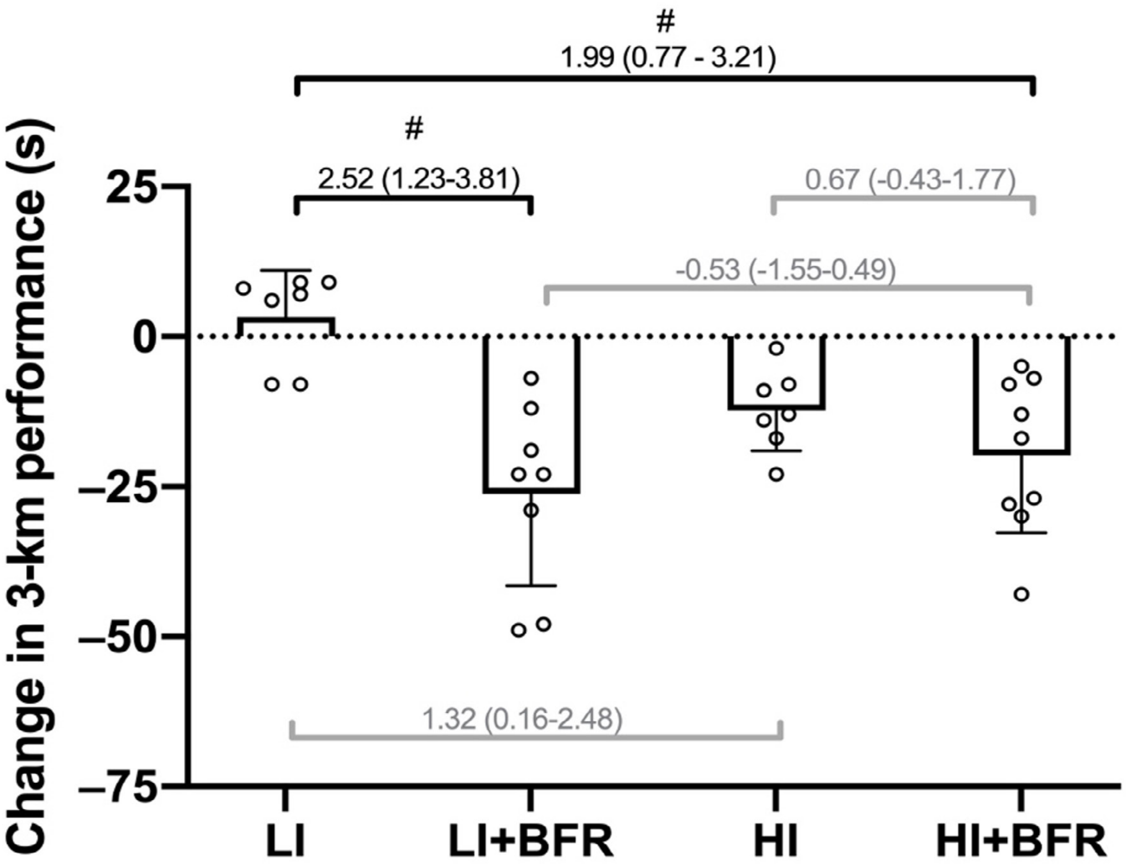

Figure 2. Changes in 3-km performance (s) in the four training groups. LI – low intensity, LI + BFR – low intensity + BFR, HI – high intensity and HI + BFR – high intensity + BFR. # - $p<0.05$ between-group comparison. Number represent Cohen's *d* with 95% confidence interval, in black when $p<0.05$ and in grey when $p>0.05$.

intervention.

However, the addition of BFR to LI resulted in greater performance improvements than LI alone, suggesting that BFR provides additional benefits to low-intensity endurance training in recreational runners. In contrast, BFR did not confer additional benefit when added to high-intensity training. Interestingly, both HI and HI+BFR improved performance, suggesting that the BFR stimulus may be redundant when high intensity training is already implemented.

Acute effects of endurance exercise include increased stroke volume, oxygen consumption, energy expenditure, and heart rate. When combined with BFR, additional physiological stress is imposed. Most evidence on BFR-induced adaptations comes from resistance training (15), where metabolite accumulation and localized hypoxia caused by external pressure are often proposed as primary drivers. Similarly, when BFR is added to LI endurance exercise, an increase in heart rate of approximately 5 bpm (16, 17) has been observed. This response has been interpreted as a result of increased peripheral resistance (18), which reduces oxygen delivery to working muscles, and is partially compensated by the concomitant rise in heart rate. We propose that this BFR-induced reduction in oxygen delivery acutely elevates cardiovascular demand (19), which in turn could stimulate angiogenesis (20, 21) or promote the enlargement of existing capillaries (22). These mechanisms might help explain the superior performance improvements observed in LI + BFR compared to LI alone. Accordingly, Chen et al. (23, 24) reported in separated studies that adding BFR to running at 50% of the heart rate reserve (a low- to moderate-intensity exercise) improved maximal running performance (as estimated by the Bruce protocol) and VO_{2max} after an 8-week training intervention. Although the studies did not assess time trial performance or vascular adaptation, the improved aerobic capacity aligns with the mechanisms proposed here.

Adding BFR to endurance exercise may have elicited additional physiological adaptations beyond those typically induced by aerobic exercise alone. These include increased resistance to fatigue, anaerobic capacity (11, 25), and muscle strength and power (26, 27). Paton et al. (28) suggested that exercising with BFR augments individual's tolerance to metabolic disturbances. Park et al. (11) reported a ~2.5% in anaerobic capacity after only two weeks of walking with BFR. Behringer et al. (27) reported that BFR applied during sprint training led to gains in rate of force development. Considering that the 3-km time-trial is typically performed near maximum aerobic speed, improvements in anaerobic capacity and muscle function may have contributed to performance gains. On the other hand, high-intensity training alone may have induced some of adaptations (29) and BFR did not augment this effect. Taken together, these findings may account for the greater efficacy of BFR when combined with low-intensity endurance training compared to low-intensity training alone.

Although the relatively short duration of our training intervention could be viewed as a limitation, multiple studies have shown that both untrained and well-trained individuals can experience significant improvements in aerobic performance, cardiorespiratory fitness, and physiological markers within a 4-week period (30-32). The review by Mølmen et al. (33) further supports this notion, reporting that some adaptations, such as angiogenesis, predominantly occur during the early stages of training. This finding aligns with our proposed mechanisms underlying the superior adaptations observed in the BFR groups.

This study is not without limitations. The major limitation is we did not investigate the magnitude of the decrease in blood flow with BFR during exercise, but we tried to increase ecological validity of the training protocol by using an elastic wrap instead of pneumatic cuffs. The small sample size with only 31 participants finishing our intervention study may limit the ability to generalize our conclusions. Although total weekly training volumes were reported, there was no systematic monitoring or standardization of training intensity, frequency, or recovery status. Also, we did not investigate markers of aerobic fitness such as VO_{2max}, metabolic thresholds, and running economy. Lactate was not analyzed during training sessions, which confers a degree of speculation when we discuss peripheral adaptations. Finally, the lack of a group that maintained habitual training limits our ability to attribute performance improvements solely to the interventions. Increases observed across training groups may partially reflect test familiarization or natural variability.

PRACTICAL APPLICATIONS

The results of this study suggest potential applications of BFR associated with low- and high-intensity endurance training bouts to improve performance. BFR can also be used if coaches and runners want to avoid performing longer volumes in situations such as return from injury or to prevent overtraining.

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CONFLICTS OF INTEREST

The authors declare they have no conflict of interests.

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ETHICAL APPROVAL

The study was approved by the Ethics Committee of the University (CAAE: 79822217.5.0000.5404).

AUTHOR CONTRIBUTIONS

All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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