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Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

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To cite this article: Tulasiram Bommasamudram, Kirtana Raghurama Nayak, Matthew J. Clarkson, Rajagopal Kadavigere, Aaron P. Russell & Stuart A. Warmington (2025) Acute responses to aerobic and bodyweight exercises with and without blood flow restriction in sedentary individuals – A randomized crossover study, Journal of Sports Sciences, 43:8, 746-755, DOI: 10.1080/02640414.2025.2474356

To link to this article: https://doi.org/10.1080/02640414.2025.2474356

JOURNAL OF SPORTS SCIENCES
2025, VOL. 43, NO. 8, 746–755
https://doi.org/10.1080/02640414.2025.2474356

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Acute responses to aerobic and bodyweight exercises with and without blood flow restriction in sedentary individuals – A randomized crossover study

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ABSTRACT
This study aimed to compare the acute cardiovascular and metabolic responses to aerobic and bodyweight resistance exercises, both with and without blood flow restriction (BFR). Sedentary individuals (8 males, 6 females) participated in four randomized exercise sessions: walking with BFR, walking without BFR, walking lunges with BFR, and walking lunges without BFR. Walking trials involved 15 minutes at 5 km.h^{-1}, while walking lunges comprised four repetition sets (30, 16, 16, 16). BFR was applied at 60% of limb occlusion pressure. Metabolic and cardiac responses were higher for walking lunges (57% $\dot{V}O_2$ max, 66% HRmax) compared with walking (47% $\dot{V}O_2$ max, 61% HRmax). BFR application increased these responses similarly for walking lunges (with BFR: 60% $\dot{V}O_2$ max, 70% HRmax) and walking (with BFR: 53% $\dot{V}O_2$ max, 63% HRmax). These similar responses suggest that bodyweight walking lunges may also be considered aerobic, like walking. Given the similarity of responses between aerobic walking and bodyweight walking lunges, and with BFR significantly enhancing the responses of both modes of exercise compared to their non-BFR equivalents, these findings suggest that practitioners have some flexibility in choice of aerobic BFR exercise modes to implement with individuals where these modes may be more suitable.

KEYWORDS
Aerobic exercise; bodyweight exercise; walking; lunge; blood flow restriction

Introduction

Blood flow restriction (BFR) training is an innovative technique that allows individuals to achieve gains in aerobic capacity, muscle size and strength using low-intensity exercises (Patterson et al., 2019). With BFR, this low-intensity training method (typically 20% of maximum) produces benefits that surpass those of similar light-intensity exercise without BFR, but less than those achieved with high-intensity training (Bennett & Slattery, 2019; Formiga et al., 2020; Grønfeldt et al., 2020). Activities to which BFR is commonly applied include low-intensity walking or cycling, and low-load resistance exercises (commonly between no external load and 40% of maximum external load) (Patterson et al., 2019). As such, BFR training is proposed to be particularly suited to populations for whom high-intensity training is not advisable, for example the sedentary, older adults or those recovering from injury (Hughes et al., 2017).

Walking combined with BFR significantly enhances aerobic capacity by 9–12% (Park et al., 2010; Thompson et al., 2024), muscle strength by 7–22% (Abe et al., 2006; Ozaki et al., 2011), and muscle mass by 3–8% (Abe et al., 2006; Ozaki et al., 2011). In contrast, walking without BFR does not typically affect aerobic capacity, strength, or muscle mass (Abe et al., 2006). Although fewer studies have focused on bodyweight resistance training with BFR, interestingly, it has been shown to produce similar improvements in strength (11–20%) (Cai et al., 2021; Yokokawa et al., 2008) and muscle mass (3–5%) (Cai et al., 2021; Kang et al., 2015) as those observed in aerobic BFR training. However, no studies have yet evaluated the effect of bodyweight resistance BFR training on aerobic capacity. Therefore, aerobic or bodyweight resistance training combined with BFR may help maintain or increase aerobic capacity, strength, and muscle mass. Thus, incorporating aerobic or bodyweight resistance training with BFR into gym or home-based prescription may benefit populations unfamiliar with or unable to perform externally loaded resistance training, such as sedentary individuals, clinical populations, or people with elevated cardiovascular risk could be considered by practitioners.

Adding BFR to walking confers greater cardiovascular stress (e.g. 2–28% greater heart rate (HR) (Loenneke et al., 2011; Sieland et al., 2021), 5–24% greater blood pressure (BP) (Ozaki et al., 2010; Walden et al., 2023), and greater metabolic demand (e.g. 11–22% greater oxygen consumption ($\dot{V}O_2$)) (Loenneke et al., 2011; Ozaki et al., 2010). However, the acute effects of

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/02640414.2025.2474356

bodyweight resistance exercises (e.g. walking lunges) with the application of BFR, remain unknown. No study has yet compared the acute physiological responses of walking and walking lunges, with or without BFR. This gap is notable despite the apparent similarities between the two activities: both involve repetitive forward movement, engage the same lower body muscles, use alternating limbs between steps and sequentially involve the hips, knees, and ankles (Keogh, 1999). However, there is some evidence of differences. For example, during walking, lower limb joint angles remain largely unchanged, resulting in a relatively consistent and stable movement pattern (Elsais et al., 2020; van der Zee et al., 2022). In contrast, walking lunges exhibit greater range of joint angles, larger mechanical stresses and ground reaction forces, resulting in greater biomechanical impacts when compared to walking (Park et al., 2021; Riemann et al., 2012). Although walking lunges impose greater biomechanical stress, the similarities between walking and walking lunges suggest that a direct comparison of their acute physiological responses is warranted. Therefore, this study aimed to compare and characterise the acute physiological responses to walking and walking lunges both with and without BFR given the similar chronic outcomes expected for each with BFR training.

Methodology

Study design

This is a prospective, randomized crossover trial. Fourteen participants (Table 1) underwent four supervised exercise sessions in a randomized order. The study was conducted according to the Declaration of Helsinki (2013), and ethics approval was obtained from Institutional Ethics Committee at Manipal Academy of Higher Education, India (IEC1–58), and Deakin University Human Research Ethics Committee, Australia (2023-–128). Additionally, the study has been registered with the Clinical Trials Registry – India (CTRI/2022/22/047383).

Participants

Sixteen sedentary participants (8 males and 8 females) were initially recruited for this study. However, for personal reasons, two females chose not to continue with the study and were subsequently excluded. This resulted in a final total of 14 participants (8 males and 6 females). For the female participants, none of the testing occurred during menstruation. Participants were classified as sedentary if their average daily step count, measured using Google FIT smartphone application over one week, was below 7,500 steps per day. Those meeting this criterion underwent a secondary screening involving a $\dot{V}O_2$ max test, conducted using the modified Bruce protocol and an indirect calorimeter (COSMED K5) (Tulasiram & Chandrasekaran, 2021). All participants were free from any musculoskeletal, neurological, or vascular diseases or injuries. Prior to participation, all individuals provided written informed consent and completed a pre-participation health screening. Exclusion criteria included diagnosed diabetes mellitus, hypertension, or the use of medication to control BP.

Table 1. Participant characteristics.

Age (years)	27 ± 2
Height (m)	1.66 ± 0.10
Weight (kg)	71.4 ± 9.3
BMI (kg.m^{-2})	26.2 ± 4.0
Step count.day^{-1}	5537 ± 1274
$\dot{V}O_{2peak}$ (ml.kg^{-1}.min^{-1})	32.4 ± 5.9
100% LoP (mmHg)	218 ± 30
60% LoP (mmHg)	132 ± 17

Experimental design

Participants were familiarized with the exercise sessions, which consisted of walking for 10 minutes at 5 km.h^{-1} and performing three sets of 16 walking lunges under BFR. The walking lunges were guided by a metronome, with 2-second concentric and eccentric phases, and 1-minute rest periods between sets. Prior to each session, they adhered to a standardized warm-up protocol as outlined by Doma et al., (2020). The exercise sessions comprised walking and walking lunges, each performed with and without BFR. A three-day washout period was implemented between sessions to prevent physiological carryover effects, minimize exercise-induced fatigue, and establish a baseline.

Walking trials

Participants engaged in a 15-minute continuous walking session at a speed of 5 km/h on a calibrated treadmill. During the BFR-walking session, the occlusion pressure set at 60% of the maximal occlusion pressure determined for each participant was applied proximally to both thighs.

Walking lunges trials

The walking lunges protocol included an initial set of 30 repetitions (15 each leg) followed by three sets of 16 repetitions (8 repetitions on each leg), with a 1-minute rest between sets. Participants performed walking lunges in sync with an auditory cue provided by a metronome, set to a beat allowing for 2-second concentric and 2-second eccentric contractions. Participants performed walking lunges with the hip flexed to 90 degrees and the knee extended to 90 degrees. For the BFR walking lunges trial, the occlusion pressure set at 60% of the maximal occlusion pressure was determined and applied proximally to both thighs. Total duration of the trail was 8.2 minutes.

Blood flow restriction

For exercise sessions using blood flow restriction, the restriction was applied during each exercise session using 10 cm wide pneumatic pressure cuffs (AirBands, VALD Health, Brisbane, Australia) positioned at the proximal end of the thigh. Total limb occlusion pressure (LOP) was determined using a pulse oximeter (NT1A Hand Held Pulse Oximeter, NEWTEC, INC, China) attached to the second toe, along with a 14.5 cm nylon blood pressure cuff (bladder width 13 cm) and a sphygmomanometer (BPMR120 Deluxe, Diamond, INC, India). This measurement was conducted with the participant in a supine position, and the cuffs were inflated until the pulse oximeter no longer detected blood flow, establishing the LOP.

During exercise sessions, the Airbands were inflated to 60% of the recorded LOP (Clarkson et al., 2017).

Maximal oxygen consumption

The maximal oxygen consumption ($\dot{V}O_2$ max) was assessed in participants using a modified Bruce treadmill protocol with an indirect calorimeter (K5, COSMED, Italy, 2014). The metabolic cart was calibrated according to the manufacturer's standards for flow (3 L syringe), room air, reference gas (CO_2:5.0%, O_2: 16%, N_2: Balance), and delay. Participants were familiarized with treadmill walking (h/p cosmos quasar, Italy) and the study protocol prior to baseline measurements. During the test, participants walked or ran on the treadmill at increasing speeds and inclinations following a warm-up, with each stage lasting 3 minutes. The protocol progressed as follows: 2.7 km/h at 0%, 5%, and 10% inclinations; 4.0 km/h at 12%; 5.5 km/h at 14%; and 6.8 km/h at 16%. In all cases, test termination was due to participant failure. However, all participants met at least three of the following criteria to confirm achievement of $\dot{V}O_2$max; a plateau in $\dot{V}O_2$, a Respiratory Exchange Ratio (RER) > 1.10, HR > 95% of age-predicted maximum (HRmax = 208–0.7 × age), Rate of Perceived Exertion (RPE) on the Borg Scale > 16. Participants were encouraged to exert maximal effort until exhaustion. $\dot{V}O_2$ data were collected breath-by-breath using the portable metabolic cart and analyzed with Omnia software, recording HR peak, peak oxygen consumption ($\dot{V}O_2$ peak), treadmill test duration, and the stage at which exhaustion or $\dot{V}O_2$ peak was achieved.

Measurements

$\dot{V}O_2$, RER, HR, and energy expenditure (EE)

Participants performed the exercise session with the COSMED K5 unit secured to their upper back, enabling continuous measurement of $\dot{V}O_2$, RER, and EE. HR data were recorded using a Polar H10 monitor, which was integrated with the COSMED K5 unit. $\dot{V}O_2$, RER, EE and HR data were continuously monitored during the exercise session and for three minutes post-exercise. All data were collected and analyzed using the Omnia software. Data were collected through continuous assessment, which included a baseline measurement, four timepoints during exercise, and a measurement taken 3 minutes post-exercise.

$\dot{V}O_2$/HR ratio, HR/RPE ratio, and $\dot{V}O_2$/RPE ratio

The $\dot{V}O_2$/HR ratio measures the change in $\dot{V}O_2$ for each unit increase in HR, the HR/RPE ratio shows how much HR increases for each unit increase in RPE, and the $\dot{V}O_2$/RPE ratio indicates the change in $\dot{V}O_2$ for each unit increase in RPE, providing insights into the relationship between physiological responses and subjective effort during exercise (Crowcroft et al., 2015; Kasiak et al., 2024). Participant data for $\dot{V}O_2$ and HR were extracted using Omnia software, while RPE were used to calculate the ratios. All ratios were calculated based on the average values recorded across the exercise timepoints only.

Blood pressure

Participants' BP was measured both before and three minutes after the exercise bout using a sphygmomanometer (Omron HEM7600T Smart Upper Arm BP Monitor, Japan). Prior to measurement, participants rested in a seated position for 5 minutes, and the post-exercise BP was also recorded while participants remained seated.

Perceptual measures

Participants rated their RPE on the Borg scale (Borg, 1982), which ranges from 6 (no exertion) to 20 (maximal exertion), at four equal intervals during a 15-minute walk and at the end of each set of walking lunges.

Sample size calculations

Sample size was calculated based on data for $\dot{V}O2$ during both BFR and non-BFR walking (Loenneke et al., 2011). Assuming a paired-samples t-test to assess mean differences between two dependent groups, with a Bonferroni correction applied to the expected α-level (0.0125) to adjust for the four planned conditions (walking – with and without BFR; walking lunges – with and without BFR) a minimum sample size of 13 participants was determined to achieve 80% power (G*Power v3.1.9.7,).

Data analysis

All statistical analyses were conducted using Jamovi version 2.5.3. All data were normally distributed according to the Shapiro-Wilk test. To evaluate the effects of the intervention on $\dot{V}O_2$, HR, RER, EE, RPE, and BP, a repeated measures ANOVA was employed. For data analysis, the exercise durations for walking and walking lunges were treated differently. The walking data were sampled at four equal intervals during a 15-minute walk: 3:45, 7:30, 11:15, and 15 minutes. The data from the last 30 seconds of each interval were averaged. For walking lunges, data were collected continuously and averaged for sampling over the final 30 seconds of each set. For $\dot{V}O_2$, HR, RER and EE these data were analyzed using a repeated measures ANOVA design to assess three factors: *Condition* (BFR and non-BFR), *Mode* (walking and walking lunges), and *Time* (baseline, T1, T2, T3, T4, and post-exercise), while for RPE *Time* points were T1, T2, T3, T4, and for BP *Time* points were baseline and post-exercise). To further compare the four trials, oxygen pulse ($\dot{V}O_2$/HR ratio) and the ratios of both HR/RPE and $\dot{V}O_2$/RPE were calculated from average exercise data across each trial. A 2-way ANOVA (*Mode x Condition*) was used for analysis of ratio data. A Tukey *Post-hoc* pair-wise comparison was used to identify specific differences. A significant level of $p < 0.05$ was adopted for all statistical tests. An η^2 (*eta* squared) of < 0.01 represents a 'small effect', 0.06 represents a 'medium effect', and values greater than 0.14 represent a 'large effect'.

Results

Participant baseline characteristics and anthropometric data align with the selection criteria, such that participants were sedentary (step count and $\dot{V}O_2$ max) (Table 1).

Oxygen consumption ($\dot{V}O_2$)

There was a significant main effect for *Time* such that $\dot{V}O_2$ increased from baseline in all trials and stabilized during exercise (T1, T2, T3, T4) before returning to a similar level to baseline post-exercise ($F = 331.3$, $p < 0.001$, $\eta^2 = 0.763$) (Figure 1). There was also a significant main effect for *Condition* such that $\dot{V}O_2$ was greater within the BFR trials than non-BFR trials ($F = 13.897$, $p = 0.003$, $\eta^2 = 0.007$). In addition, there was a significant main effect for *Mode* such that $\dot{V}O_2$ was greater during the walking lunge trials compared with the walking trials ($F = 30.253$, $p < 0.001$, $\eta^2 = 0.028$). There were no significant interactions for *Condition x Time*, or *Condition x Mode*. However, there was a significant interaction for *Mode x Time* such that $\dot{V}O_2$ at baseline and post-exercise were similar between the walking and walking lunge trials, whereas at all exercising timepoints, $\dot{V}O_2$ was greater with walking lunges compared with walking ($F = 14.998$, $p < 0.001$, $\eta^2 = 0.018$). In addition, although a significant three-way interaction was found among *Condition x Time x Mode*, the *post-hoc* analysis did not reveal any further significant differences to those observed through the main effects or two-way interactions ($F = 2.658$, $p = 0.030$, $\eta^2 = 0.002$).

Heart rate (HR)

There was a significant main effect for *Time* such that HR increased from baseline in all trials and stabilized during exercise (T1, T2, T3, T4) before returning to a similar level to baseline post-exercise ($F = 99.513$, $p < 0.001$, $\eta^2 = 0.365$) (Figure 2). There was also a significant main effect for *Condition* such that HR was greater within the BFR trials than non-BFR trials ($F = 7.371$, $p = 0.018$, $\eta^2 = 0.019$). In addition, there was a significant main effect for *Mode* such that HR was greater during the walking lunge trials compared with the walking trials ($F = 12.866$, $p = 0.003$, $\eta^2 = 0.042$). There were no significant interactions for *Condition x Time, Condition x Mode*, or *Mode x Time* and no significant three-way interaction for *Condition x Time x Mode*.

Respiratory exchange ratio (RER)

There was a significant main effect for *Time* such that RER increased from baseline to T1 and again to T2, after which RER declined to T3 and T4, yet still being greater than T1. RER increased post-exercise to the highest values observed across time in all trials ($F = 13.38$, $p < 0.001$, $\eta^2 = 0.108$) (Figure 3). There was no significant main effect for *Condition*. In addition, there was a significant main effect for *Mode* such that RER was greater during the walking lunge trials compared with the walking trials ($F = 51.19$, $p < 0.001$, $\eta^2 = 0.287$). However, there was no main effect for *Condition* and no significant interaction for *Condition x Mode*. There was a significant interaction for *Mode x Time* such that RER at baseline, T1, T3, and post-exercise were similar between walking trials and walking lunge trials,

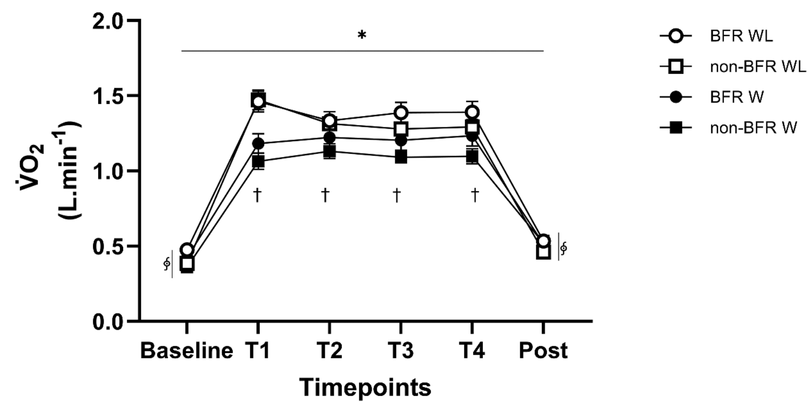

Figure 1. Oxygen consumption ($\dot{V}O_2$) over time. indicates a significant main effect of time, where baseline and post-exercise are less than T1 - T4 ($p < 0.05$). * indicates a significant main effect for both condition, and mode, whereby BFR trials are greater than non-bfr trials, and walking lunges trials are greater than walking ($p < 0.05$). † indicates a significant interaction such that $\dot{V}O_2$ during walking lunges is significantly greater than during walking at all exercise timepoints (T1 - T4) ($p < 0.05$). Data are presented as mean ± SEM.

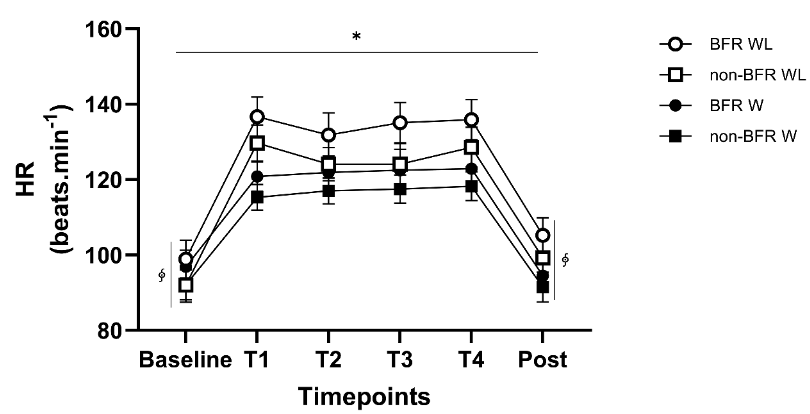

Figure 2. Heart rate (HR) over time. indicates a significant main effect of time, where baseline and post-exercise are less than T1 - T4 ($p < 0.05$). * indicates a significant main effect for both condition, and mode, whereby BFR trials are greater than non-bfr trials, and walking lunges trials are greater than walking ($p < 0.05$).

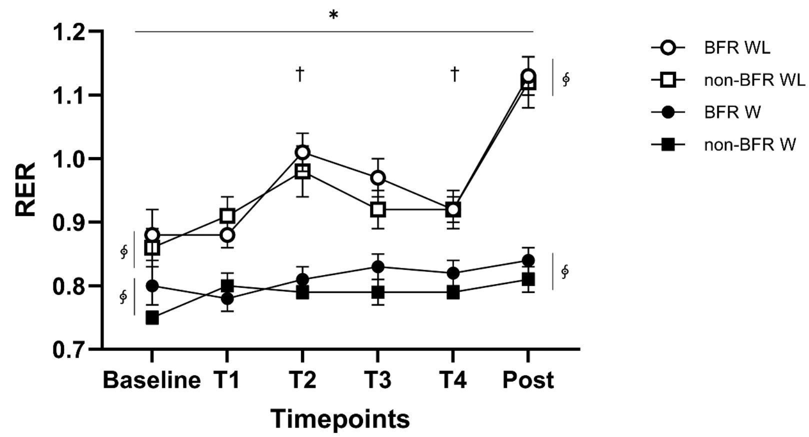

Figure 3. Respiratory exchange ratio (RER) over time. indicates a significant main effect of time, where increase from baseline to T1 and T2, decrease in T3, T4 and increase in post-exercise ($p < 0.05$). * indicates a significant main effect for both condition, and mode, whereby walking lunges trials are greater than walking ($p < 0.05$). † indicates a significant interaction such that RER during walking lunges is significantly greater than during walking at T2 and T4 ($p < 0.05$). Data are presented as mean ± SEM.

whereas at T2 and T4, RER was greater in walking lunge trials compared with walking trials (F = 14.33, $p < 0.001$, $\eta^2 = 0.079$). Additionally, there was a significant interaction for *Condition x Time* (F = 2.98, $p = 0.018$, $\eta^2 = 0.01$), but *post-hoc* analysis did not reveal any significant differences. No significant three-way interaction was found for *Condition x Time x Mode* for RER.

Energy expenditure (EE)

There was a significant main effect for *Time* such that EE increased from baseline in all trials and stabilized during exercise (T1, T2, T3, T4) before returning to a similar level to baseline post-exercise (F = 322.596, $p < 0.001$, $\eta^2 = 0.749$) (Figure 4). There was also a significant main effect for *Condition* such that EE was greater within the BFR trials than non-BFR trials (F = 12.118, $p = 0.003$, $\eta^2 = 0.008$). In addition, there was a significant main effect for *Mode* such that EE was greater during the walking lunge trials compared with the walking trials (F = 39.61, $p < 0.001$, $\eta^2 = 0.041$). There were no significant interactions for *Condition x Time* or *Condition x Mode*. However, there was a significant interaction for *Mode x Time* such that EE at baseline and post-exercise were not different (and also at T2) for walking and walking lunge trials, whereas at the exercise time points T1, T3, and T4, EE was greater during the walking lunge trials compared with walking trials (F = 16.578, $p < 0.001$, $\eta^2 = 0.019$). In addition, although a significant three-way interaction was found among *Condition x Time x Mode*, the *post-hoc* analysis did not reveal any further significant differences to those observed through the main effects or two-way interactions (F = 2.682, $p = 0.029$, $\eta^2 = 0.002$). The mean EE for the trail was 26 kcal for walking lunges, 27 kcal for walking lunges with BFR, 21 kcal for walking, and 23 kcal for walking with BFR.

Rating of perceived exertion (RPE)

There was a significant main effect for *Time* such that RPE increased successively for each timepoint from T1 to T4 (F = 34.111, $p < 0.001$, $\eta^2 = 0.081$) (Figure 5). There was also a significant main effect for *Condition* such that RPE was greater within the BFR trials than non-BFR trials (F = 24.321, $p < 0.001$, $\eta^2 = 0.051$). In addition, there was a significant main effect for *Mode* such that RPE was greater during the walking lunge trials compared with the walking trials

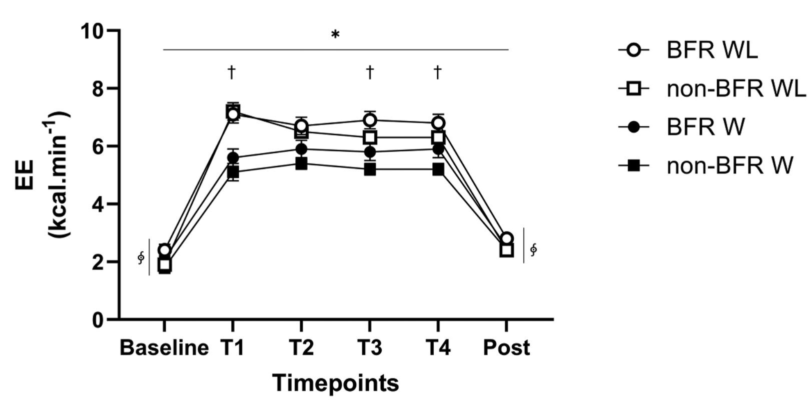

Figure 4. Energy expenditure (EE) over time. indicates a significant main effect of time, where baseline and post-exercise are less than T1 - T4 ($p < 0.05$). * indicates a significant main effect for both condition, and mode, whereby BFR trials are greater than non-bfr trials, and walking lunges trials are greater than walking ($p < 0.05$). † indicates a significant interaction such that EE during walking lunges is significantly greater than during walking at T1, T3, and T4 ($p < 0.05$). Data are presented as mean ± SEM.

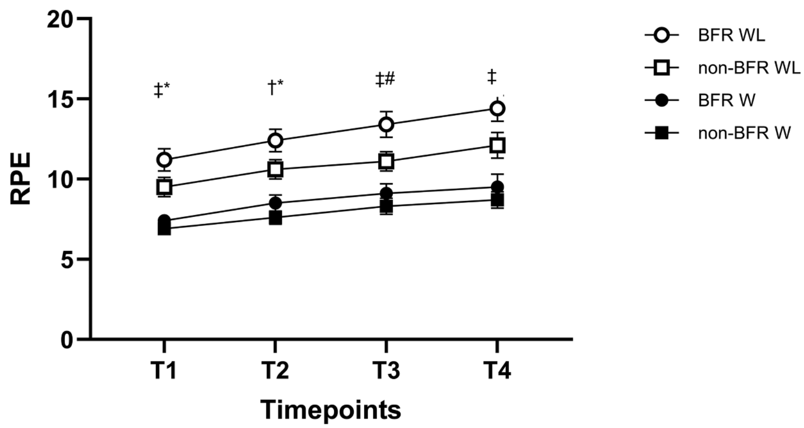

Figure 5. Rating of perceived exertion (RPE) over time. † BFR walking trials significantly higher than non-bfr walking trials ($p < 0.05$). ‡ BFR walking trials significantly higher than non-bfr walking trials ($p < 0.05$) and walking lunges significantly higher than walking ($p < 0.05$). * significantly higher compared with T3 and T4; # significantly higher compared with T1, T2 and T4 ($p < 0.05$). Data are presented as mean ± SEM.

($F = 61.772$, $p < 0.001$, $\eta^2 = 0.081$). There was a significant interaction between *Condition x Mode*, with RPE being higher during BFR walking lunges trials compared to both non-BFR walking lunges trials and BFR walking trials, whereas no difference was observed between BFR and non-BFR walking trials ($F = 6.850$, $p = 0.021$, $\eta^2 = 0.011$). Additionally, there was a significant interaction for *Condition x Time*, with T1, T3, and T4 showing higher RPE with BFR trials compared to non-BFR trials, but T2 showed no difference between these trials ($F = 3.109$, $p = 0.037$, $\eta^2 = 0.001$). Furthermore, there was a significant interaction for *Mode x Time*, such that RPE was great with walking lunges at all exercise timepoints compared with walking ($F = 3.510$, $p = 0.024$, $\eta^2 = 0.003$). No significant three-way interaction for *Condition x Time x Mode* was found for RPE.

Blood pressure (BP)

There was no significant main effect for *Time* or *Condition*. There was a significant main effect for *Mode* such that systolic BP (sBP) was higher during the walking lunge trials compared to walking trials ($F = 10.397$, $p = 0.007$, $\eta^2 = 0.054$). Additionally, there was a significant interaction for *Mode x Time*, such that sBP was higher post-exercise in the walking lunge trials compared with walking trials, while no difference was observed pre-exercise ($F = 12.809$, $p = 0.003$, $\eta^2 = 0.037$). There were no significant interactions for *Condition x Time* or *Condition x Mode*, and no significant three-way interaction for *Condition x Time x Mode* for sBP. Diastolic BP and mean arterial pressure (MAP) did not exhibit any main effects or interactions, except for MAP, which showed a significant *Time x Mode* interaction. However, *post-hoc* analysis did not reveal any further significant differences.

Oxygen pulse (ml.Beat-1)

There was no significant main effect for *Condition*. There was a significant main effect for *Mode* such that oxygen pulse was greater during the walking lunge trials compared with the walking trials ($F = 6.023$, $p = 0.029$, $\eta^2 = 0.059$) Figure 6(a). There was no significant interaction (*Mode* x *Condition*).

HR/RPE (beat.rating^{-1}) ratio

There was a significant main effect for *Condition* such that HR/RPE ratio was greater within the non-BFR trials than BFR trials ($F = 5.109$, $p = 0.042$, $\eta^2 = 0.018$). There was a significant main effect for *Mode* such that HR/RPE ratio was greater during the walking trials compared with the walking lunge trials ($F = 20.779$, $p < 0.001$, $\eta^2 = 0.214$) Figure 6(b). There was no significant interaction (*Mode* x *Condition)*.

$\dot{V}O_2$/RPE (ml.rating^{-1}) ratio

There was no significant main effect for *Condition*. There was a significant main effect for *Mode* such that $\dot{V}O_2$/RPE ratio was greater during the walking trials compared with the walking lunge trials ($F = 7.56$, $p = 0.017$, $\eta^2 = 0.083$) Figure 6(c). There was a significant interaction between *Mode* x *Condition*, with *post-hoc* indicating walking lunges with BFR is lower than all other trails ($F = 4.83$, $p = 0.019$, $\eta^2 = 0.017$).

Additionally, we conducted a sex-based comparison for all outcome variables; however, no significant differences were observed between males and females.

Discussion

The main findings of the present study indicate that walking lunges, considered a light-moderate intensity bodyweight resistance exercise, imposes a small but significantly greater cardiovascular stress and metabolic demand compared to walking alone. Furthermore, the application of BFR to both walking and walking lunges also results in a significant but small increase in the cardiovascular stress and metabolic demand compared to non-BFR walking and non-BFR walking lunges, respectively.

The light-moderate intensity cardiovascular and metabolic requirements of walking in the present study demonstrate the aerobic nature of walking (Table 2). While there was a small but

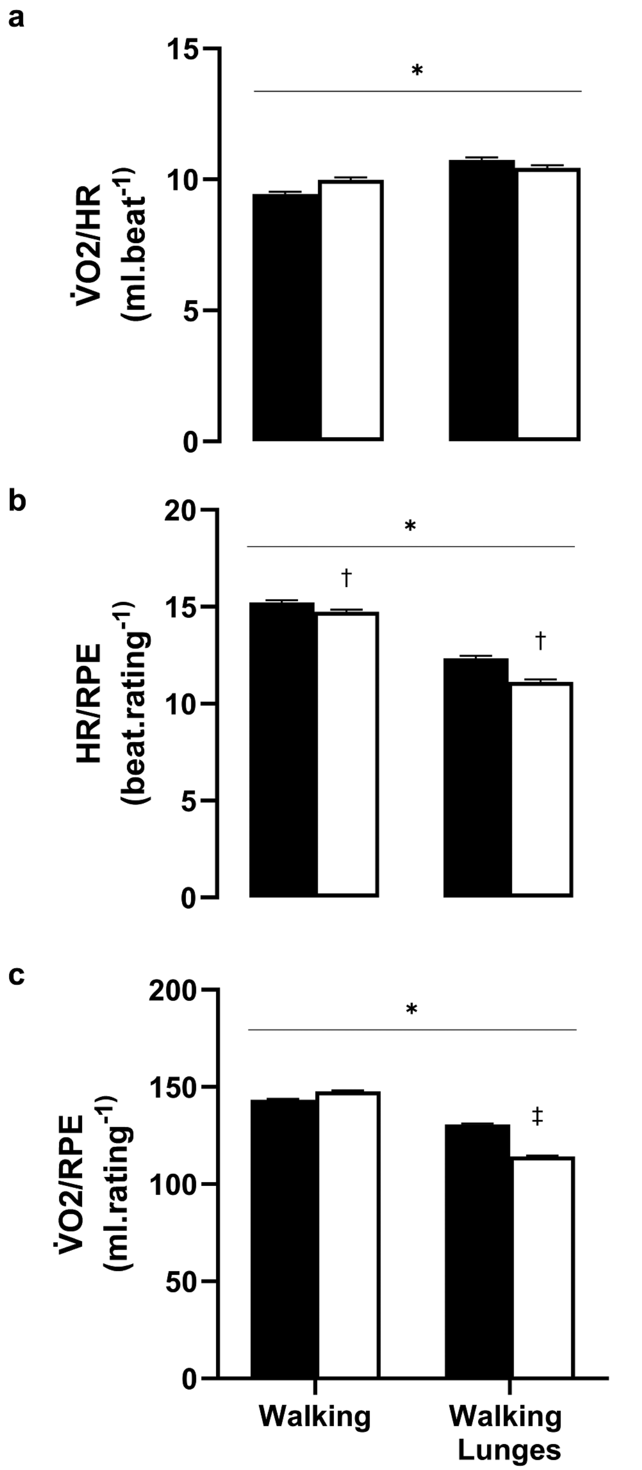

Figure 6. HR, $\dot{V}O_2$ and RPE ratio data. A) Oxygen pulse ($\dot{V}O_2$/HR); B) HR/RPE ratio; C) $\dot{V}O_2$/RPE ratio. * significant main effect for mode with walking trials being greater than walking lunge trials ($p < 0.05$). † significant main effect for condition with non-bfr trials being greater than BFR trials ($p < 0.05$). ‡ significant interaction for mode and condition such that walking lunges with BFR is less than all other trials ($p < 0.05$). Black bars represent non-bfr trial, while white bars represent BFR trails. Data are presented as mean ± SEM.

significant increase in cardiovascular and metabolic demands with walking lunges, these still represent a 'light-moderate' intensity and suggest walking lunges to be somewhat aerobic despite commonly being considered a bodyweight 'resistance' exercise (Table 2). In contrast, higher intensity aerobic activities like jogging elicit greater cardiovascular, metabolic and perceptual responses than those observed in the present study (e.g. 50–70% $\dot{V}O_2$ max, 60–75% HRmax, 0.85 RER) (Carter et al., 2002; Dias et al., 2014; Diebel et al., 2017; Hunt et al., 2015), with these being even greater with high-intensity aerobic training (e.g. ≥70% $\dot{V}O_2$ max, ≥80% HRmax, ≥0.93 RER) (Cipryan et al., 2017; Dias et al., 2014; Thomas et al., 2005; Unhjem, 2024) or traditional resistance training (e.g. 40–45% $\dot{V}O_2$ max, 50–65% HRmax, ≥0.9 RER) (Haddock & Wilkin, 2006; Lässing et al., 2023; Wingfield et al., 2015). Collectively, this suggests that walking or walking lunges are both relatively light-moderate intensity exercises that may be prescribed interchangeably in scenarios where high-intensity resistance or aerobic exercises may be contraindicated.

While an increase in cardiovascular and metabolic responses to walking and walking lunges is expected, the present study reveals that adding BFR to these activities leads to a small yet significant increase in these demands (Table 2). Interestingly, even with BFR, the intensity of walking and walking lunges remains within the light to moderate range. This suggests that BFR can enhance the training stimulus without pushing the exercises into high-intensity zones. Consequently, BFR-enhanced walking and walking lunges provide a more accessible mode of training for those who may not be able to engage in high-intensity exercise due to physical limitations or health concerns. The greater cardiovascular and metabolic demand of BFR walking and walking lunges is likely associated with the greater improvements in aerobic capacity, strength and muscle hypertrophy compared to non-BFR equivalent exercise (6–7, 9, 11–12). However, it is important to recognise the greater perceptual demands with these BFR exercise modes despite the light-moderate intensity (Walden et al., 2023). Importantly, further research is needed to understand the long-term chronic training adaptations. For practitioners and trainers, this presents an opportunity to design exercise programs tailored to individual client needs and preferences.

Similar to the cardiovascular and metabolic demands, walking lunges elicited a significantly higher RPE compared to walking, reflecting the greater perceived effort during walking lunges. In addition, the application of BFR elevated RPE further in both walking and walking lunge trials. Although the present study did not compare these exercises against higher-intensity activities (e.g. jogging with an RPE of 10–13, high-intensity aerobic training with an RPE of ≥ 14, or resistance training with an RPE of ≥ 15) (Cipryan et al., 2017; Dias et al., 2014; Lässing et al., 2023; Unhjem, 2024; Wingfield et al., 2015), the RPE for BFR walking lunges (~13) suggests walking lunges may be perceived as higher intensity and the perception of the exercise is greater than expected based on the cardiovascular and metabolic demands. This higher RPE might be attributed to greater muscle tension from the larger changes in joint angles during lunges (Keogh, 1999), potentially promoting greater strength gains while maintaining the light-moderate cardiovascular and metabolic demands similar to BFR walking. This distinction is important for practitioners when designing exercise programs, as BFR walking lunges may offer additional strength benefits without exceeding the intended cardiovascular and metabolic load.

Table 2. Summarized cardiovascular and metabolic requirements of walking and walking lunges with and without blood flow restrictions. $\dot{V}O_2$peak, peak oxygen consumption; HR_{max}, maximum heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion.

Outcome variable	non-BFR walking	BFR walking	non-BFR walking lunges	BFR walking lunges
$\dot{V}O_{2peak}$	47%	53%	57%	60%
HR_{max}	61%	63%	66%	70%
RER	0.79	0.81	0.93	0.94
RPE	7.9	8.6	11	12.9

This is reflected in the ratio data (HR/RPE, $\dot{V}O_2$/RPE, Figure 6 (b,c), where walking lunges show lower values compared to walking. For example, during non-BFR walking lunges, the increase in HR is 23% less for each unit increase in the RPE compared to non-BFR walking. When using BFR, this effect is even more pronounced, with the increase in HR being 32% less per unit increase in RPE during BFR walking lunges compared to BFR walking. This suggests that walking lunges with BFR are perceived as more difficult (higher RPE) but result in a smaller-than-expected increase in cardiovascular and metabolic demands, as evidenced by the lower ratio; i.e. lower heart rate increase per unit of RPE. Thus, walking lunges may be a more beneficial exercise to recommend, especially if the training outcomes are similar to aerobic exercise (Abe et al., 2006; Cai et al., 2021; Ozaki et al., 2011; Yokokawa et al., 2008). Walking lunges (with BFR) offer the greatest cardiovascular and metabolic demands of the four trials in the present study, but they also result in the greatest RPE. As such, while walking lunges require no extra space or equipment, making them a practical option for long-term fitness improvements, they appear to be approaching a limit of tolerance based on RPE despite maximizing the potential for cardiovascular and metabolic improvements. While BFR walking is well-known for enhancing muscle strength and endurance (Abe et al., 2010; Thompson et al., 2024), there is a lack of research on bodyweight BFR training, particularly for exercises like walking lunges. Therefore, studies comparing the long-term adaptations of these exercise methods are needed to provide practitioners with well-informed options for incorporating BFR into training routines and to understand the compliance to these exercise protocols, especially if exercising at home.

To the best of our knowledge, this is the first study to examine the cardiovascular and metabolic responses to BFR bodyweight exercise and compare aerobic and bodyweight exercise responses. It provides valuable insights into how aerobic and bodyweight BFR exercises compare in terms of cardiorespiratory, metabolic, and perceptual responses. One limitation is that BP was measured at baseline and three minutes post-exercise, a measurement frequency that limited our ability to observe potential variations in BP across *Time*, *Condition*, and *Mode*. However, given the small impact of BFR on other outcome measures, the impact of this limitation would appear insignificant. We did not provide participants with a standardized nutritional plan during the study period but advised them to consume a meal at least three hours prior to the testing session. However, the composition of meals was neither monitored nor controlled. Additionally, although the LOP was measured using a 13 cm bladder cuff, the implementation was performed using a 10 cm Airband. This difference may have resulted in a slight underestimation of LOP. This study focused solely on sedentary participants, which limits the generalizability of the findings to other populations, such as those who are recreationally active or trained. However, our data do not suggest that the measured responses would differ significantly in these groups. Further research is needed to determine whether the observed effects are consistent across populations with different levels of physical activity and training. Our findings are based on systemic measures, but additional local measures, such as muscle metabolite accumulation, hemoglobin parameters, or arterial stiffness, could provide valuable insights in future studies examining aerobic outcomes of BFR exercise. In addition, future studies should also focus on sex-based comparison in long-term training studies.

Conclusion

This study demonstrates that the cardiovascular and metabolic demand of walking lunges is greater than for walking, although both exercises remain within the light-moderate intensity range. The addition of BFR modestly increases these demands, yet the overall intensity of the exercises remains within the light-moderate intensity range. Interestingly, while both walking and walking lunges are demonstrated to be light-to-moderate exercises through the cardiovascular and metabolic demand, these are elevated with the addition of a BFR. The progressively higher RPE from walking-to-walking lunges and from non-BFR to BFR exercise suggests that, despite both being light-to-moderate exercises, walking lunges particularly with the addition of BFR may be perceived as more intense than walking with BFR and their non-BFR equivalents. However, given walking lunges (with BFR) produce the greatest cardiovascular and metabolic response, this mode is likely the most effective to improve aerobic outcomes with training. This finding is important for exercise prescription, as it provides insight into how these low-impact exercises, with or without BFR, can be used effectively and progressively in scenarios where higher-intensity exercise is contraindicated. Further research is needed to explore the chronic adaptations to these exercises, particularly in populations where low-intensity training is preferred.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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Data availability statement

The data presented in this study are available on request from the First or Corresponding author.

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