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Research article

Negative effects of blood flow restriction on perceptual responses to walking in healthy young adults: A pilot study

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ABSTRACT

Background: Blood flow restriction (BFR) exercise is recognized as a beneficial strategy in increasing skeletal muscle mass and strength. These positive effects can also be obtained by a mild exercise mode such as walking. However, BFR exacerbates some perceptual responses, such as perceived exertion response, induced by exercise. Despite this knowledge, the negative effects of BFR exercise on major perceptual parameters related to exercise adherence remain unknown. Furthermore, compared with other exercise modes (e.g., resistance exercise), little is known regarding the effects of BFR on perceptual responses to walking. To clarify these issues, we examined the effects of BFR walking on perceptual parameters, including exercise adherence-related parameters.

Methods: Eighteen healthy, young males performed both BFR and non-BFR (NBFR) walking on a treadmill in a crossover design. Exercise was performed as five sets of 2-min walking with 1-min rest intervals. BFR walking was performed with 200 mmHg pressure cuffs placed around the proximal region of the thighs. NBFR walking was performed without pressure cuffs.

Results: Ratings of perceived exertion and leg discomfort were significantly higher during BFR walking than during NBFR walking. Affect and task motivation were significantly lower during BFR walking than during NBFR walking; by contrast, perceived pain was significantly higher during BFR walking than during NBFR walking. Enjoyment immediately after walking was significantly lower with BFR than with NBFR.

Conclusions: These findings suggest that BFR walking induces greater responses of perceptual parameters, including exercise adherence-related parameters, than does NBFR walking. Therefore, BFR walking may decrease adherence to this exercise. To further popularize BFR exercise, further studies are needed to develop effective strategies to minimize the BFR-induced negative effects on perceptual responses.

1. Introduction

Physical inactivity and sedentary lifestyles are recognized as public health problems worldwide. Long-term interventions of both resistance and aerobic exercises result in numerous health improvements in various populations [1]. However, these exercises require considerable physical loads, especially for older individuals and patients with chronic diseases who often have difficulty in performing effective exercise programs with high-intensity due to declining health of the cardiovascular and musculoskeletal systems. Furthermore, high-intensity exercise results in elevated perceptual responses, including increased perceived exertion and decreased affect, which can be considered barriers to exercise participation on the part of some individuals [2, 3]. Therefore, novel exercise mode(s) with low-intensity exercise that can obtain many health improvements similar to those of high-intensity exercise and can be performed with lower perceptual responses than those of high-intensity exercise would be useful in improving exercise adherence in various populations.

Blood flow restriction (BFR) exercise is a unique method that employs low-intensity loads of resistance and aerobic exercises [4, 5, 6, 7, 8]. Despite the fact that it is a low-intensity exercise, BFR exercise is known to lead to muscle hypertrophy and strength gain dramatically in various populations, including older individuals and patients with chronic diseases [4, 5, 6, 7, 8]. Importantly, these positive effects can also be obtained by walking [9, 10], which is a basic locomotion and mild exercise mode, potentially via increasing endocrine hormone secretion and muscle protein synthase signaling [9, 11]. Furthermore, BFR walking

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improves various physical functions, including aerobic capacity [9, 10, 12]. Therefore, BFR exercises, including walking, have attracted a great deal of attention in many exercise/sports scientific fields.

Nevertheless, previous studies determined that BFR exercises result in elevated responses of perceptual parameters [12, 13, 14, 15, 16, 17, 18, 19, 20, 21]. For example, low-intensity resistance exercise-induced increases in perceived exertion such as the ratings of perceived exertion (RPE) and leg discomfort were greater with BFR than with non-BFR (NBFR) [13, 14, 15, 21]. Moreover, the ratings of these perceived exertion parameters during low-intensity resistance exercise with BFR were similar to or higher than those during traditional high-intensity resistance exercise [13, 14, 15]. Furthermore, Silva et al. [18] determined that mood states decreased after low-intensity resistance exercise with BFR, while they did not observe this after low-intensity resistance exercise with NBFR. Additionally, similar to the findings from BFR resistance exercise, a couple of studies by Silva et al. [19, 20] also reported that perceptual responses induced by low-intensity aerobic exercise with BFR were greater than those induced by low-intensity aerobic exercise with NBFR and similar to those induced by high-intensity aerobic exercise. These previous findings suggest that BFR aerobic and resistance exercises have negative effects on perceptual responses, which may decrease adherence to both exercise modes on the part of some individuals.

Despite this knowledge, no study to date has examined negative effects of BFR exercises on major perceptual parameters (e.g., affect, task motivation, and enjoyment) related to exercise adherence; thus, the negative effects of BFR exercise on perceptual parameters have not been fully recognized. Furthermore, compared with other exercise modes (e.g., resistance exercise), little is known regarding the effects of BFR on perceptual responses to a mild form of exercise such as walking. Previous studies reported that the degree of changes in perceptual parameters, including exercise adherence-related parameters, induced by exercise may be at least partially dependent on magnitude of some physiological responses, such as cardiovascular (e.g., heart rate [HR]) and metabolic (e.g., blood lactate) responses, during this exercise [22, 23]. Additionally, previous studies reported that BFR resulted in increases in these physiological responses, including cardiovascular and metabolic responses, during walking [9, 11]. Therefore, we hypothesized that BFR walking would induce negative responses of exercise adherence-related perceptual parameters, similar to perceived exertion parameters and mood statuses, as compared to NBFR walking. To test this hypothesis, we compared the effects of BFR and NBFR walking on these perceptual responses in healthy young adults.

2. Methods

2.1. Subjects and ethics

Eighteen healthy, young males (age: 21.1 ± 0.5 years) participated in this study. To determine the required sample size of this study, we utilized effect size (0.27–0.60) on the two previous studies [24, 25], which examined changes in perceptual parameters (i.e., RPE and affect) induced by exercise, with a 2 × >7 two-way repeated-measures analysis of variance (ANOVA). The α- and β-levels employed 0.05 and 0.2 (80% power), respectively. The calculated necessary number of subjects was 6–16; thus, we considered that the number of subjects recruited in this study was sufficient for ensuring statistical power and sensitivity. The subjects were recreationally active and participated in physical exercise (e.g., resistance exercise and/or aerobic exercise) for 2–4 h per week. The subjects were free of any known neurological, cardiovascular, and pulmonary disorders. The subjects were instructed to avoid strenuous physical activity in the 24 h prior to each experimental session. Each subject also abstained from food, caffeine and alcohol for 12 h prior to each experiment, and was not taking any medications that may affect perceptual responses. All subjects provided written informed consent upon having the experimental procedures and potential risks described to them. The study was approved by the Ethics Committee of Ritsumeikan University and conducted according to the Declaration of Helsinki.

2.2. Experimental design

This study used a crossover design, whereby all subjects completed the two experimental sessions with BFR and NBFR, with a randomized and counterbalanced order. Each subjects made a total of three visits to the laboratory over approximately two weeks. On the first visit, subjects received a detailed explanation of the experimental protocols and perceptual parameters. Then, their anthropometrical parameters were measured. After measurements were completed, the subjects were familiarized with the BFR maneuver at a sitting resting position using the familiarization method (see **Experimental condition**) to minimize an excessive response to BFR due to lack of experience with BFR exercise.

Experimental procedures of BFR and NBFR walking sessions are presented in Figure 1. On the day of the experiments (i.e., second and third visits), subjects performed either with BFR or NBFR walking on a treadmill (Life Fitness 95T; Life Fitness, Schiller Park, IL, USA). Cardiovascular (HR and blood pressure) and psychological parameters (affect, task motivation, and perceived pain) were measured throughout experimental session (i.e., before and during walking exercise, and the 30-min post-exercise period). Physiopsycological parameters (i.e., RPE and leg discomfort) were measured before and during walking. Blood metabolites (i.e., blood glucose and lactate) and mood profiles were measured before and immediately after walking, and the 30-min post-exercise period. Enjoyment was measured immediately after walking.

2.3. Experimental conditions

Exercise was programmed for five sets of 2-min walking at 5 km/h with 1-min rest intervals. In the BFR waking session, tourniquet cuffs were wrapped around the proximal region of the thighs. To familiarize the subject with the BFR maneuver, the occlusion pressure was initially inflated at 100 mmHg for 30 s and then released for 10 s in sitting position. Following the first BFR familiarization, the BFR pressure was gradually increased by 25 mmHg with 30-s holding and 10-s releasing. This BFR familiarization process was repeated until a final occlusion pressure at 200 mm Hg was reached. Immediately before the BFR waking session, the occlusion pressure for BFR was inflated in a standing position and this pressure remained until the cessation of the last exercise bout. During BFR walking, the BFR pressure was carefully checked by examiners. In the NBFR walking session, subjects stood by sitting rest for a same time (i.e., about 4–5 min) of the BFR familiarization and then performed same exercise protocol as the BFR waking, without the application of a pressure cuffs.

2.4. Cardiovascular parameters

HR was measured continuously via telemetry (RS400; Polar Electro Japan, Tokyo, Japan). Systolic blood pressure and diastolic blood pressure were measured using a mercury manometer (FC-110ST; Focal, Chiba, Japan). Mean arterial pressure (MAP) was calculated as [(systolic blood pressure – diastolic blood pressure)/3 + diastolic blood pressure].

2.5. Blood metabolites

Fingertip blood samples were collected to determine blood metabolite responses. Blood glucose and lactate levels were measured using glucose (Glutest Neo α; Sanwa Kagaku Kenkyusho, Nagoya, Japan) and lactate (Lactate Pro 2; Arkray, Kyoto, Japan) analyzers, respectively.

2.6. RPE and leg discomfort

The Borg's 15-point Scale was collected to assess RPE, which ranging from 6 (no exertion) to 20 (maximal exertion) [26]. The Borg's Category-Ratio Scale was collected to assess the rating of leg discomfort,

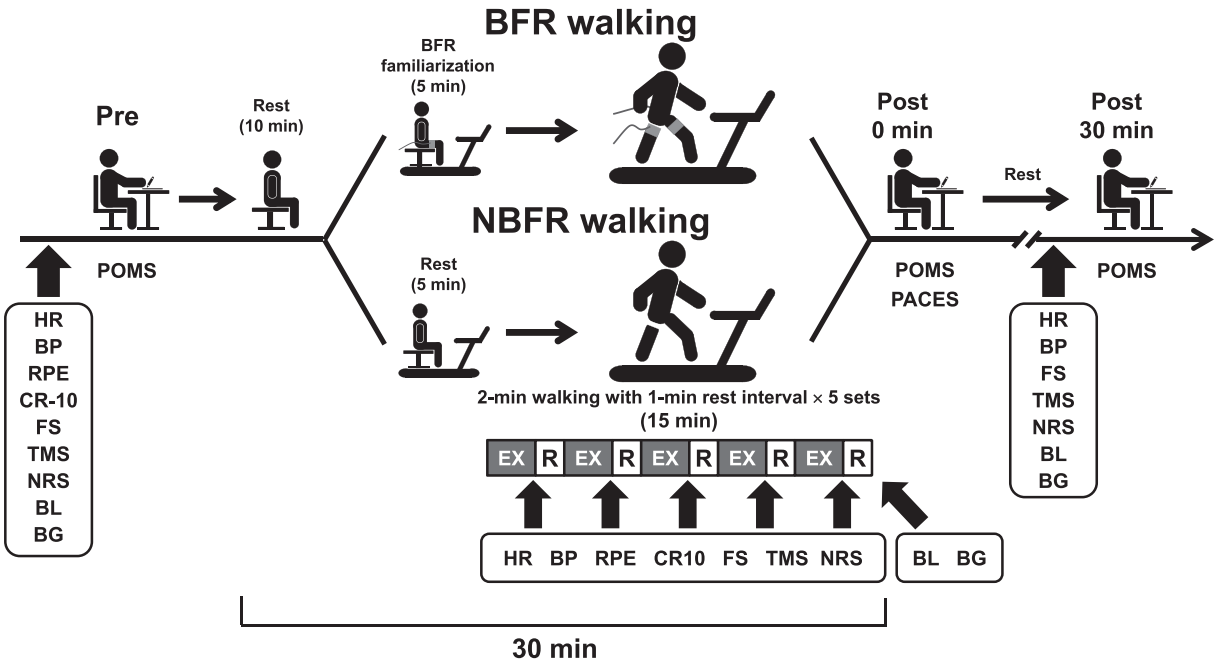

Figure 1. Experimental procedures of blood flow restriction (BFR) and non-BFR (NBFR) walking sessions. Subjects performed either with BFR or NBFR treadmill walking o in a randomized and counterbalanced order. Cardiovascular (heart rate [HR] and blood pressure [BP]) parameters, the Feeling Scale (FS)-measured affect, the Task Motivation Scale (TMS)-measured task motivation, and the Numerical Rating Scale (NRS)-measured perceived pain were collected throughout experimental session (i.e., before walking, during walking, and 30-min after walking). The ratings of perceived exertion (RPE) and leg discomfort measured using the Borg's 15 point and category-ratio (CR-10) scales were collected before and during walking. Blood metabolites (i.e., blood lactate [BL] and glucose [BP]) and the Profile of Mood States (POMS)-measured mood states were collected before walking, immediately after walking, and 30-min after walking. The Physical Activity Enjoyment Scale (PACES)-measured enjoyment was collected immediately after walking.

which ranges from 0 (nothing at all) to 10 (very, very strong) [24]. These perceived exertion scales have been established as reliable and valid measures of physical exertion for acute exercise [26, 27, 28, 29].

2.7. Affect

Affect was measured using the Feeling Scale (FS) [30]. The FS is an 11-point bipolar scale, which ranges from -5 (very bad) to 5 (very good) with further descriptions at -3 (bad), -1 (fairly bad), 0 (neutral), 1 (fairly good), and 3 (good). The FS has been established as a reliable and valid measure of affective response for acute exercise [30, 31].

2.8. Task motivation

Task motivation was measured using the Task Motivation Scale (TMS) [32]. The TMS is an 11-point scale, which ranges from 0 (nothing) to 10 (extremely strong) with further descriptions at 2 (weak), 5 (moderate), 8 (strong). Although the TMS has no information as a reliable and valid measure during exercise, it has been used to measure task motivation of acute exercise in previous studies [32, 33].

2.9. Perceived pain

Perceived pain was measured using the Numerical Rating Scale (NRS) [34]. The NRS is an 11-point scale with descriptions at 0 (no pain at all), 5 (moderate pain), and 10 (worst pain imaginable). The NRS has been established as a reliable and valid measure of pain intensity [34, 35]. This scale has also been used to measure acute pain intensity induced by BFR in previous studies [36, 37].

2.10. Mood

Mood states were measured using a short version of the Profile of Mood States (POMS) [38]. This version is consisted of 35 questions and can be evaluated at 6 mood profiles: anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension -anxiety and vigor-activity. The total mood disturbance (TMD) score was calculated based on methodology of the previous study [36]. The POMS has been established as a reliable and valid measure of mood profiles [38, 39] and a reactive measure of acute exercise [40, 41].

2.11. Enjoyment

Enjoyment was measured using the Physical Activity Enjoyment Scale (PACES) [42]. The PACES is consisted of 18 questions, which is a total of 7 positive and 11 negative questions. Subjects are required to rate on a 7-point scale (1–7) at each questions. The total score was used for analysis of this study. The PACES has been established as a reliable and valid measure of physical activity enjoyment [42, 43] and a reactive measure of acute exercise [24, 33, 44, 45, 46, 47, 48].

2.12. Measurements of anthropometrical parameters

Body height was measured using a stadiometer under barefoot condition. Body weight and whole-body skeletal muscle and fat masses were measured using a bioelectrical impedance analysis with multiple impedance frequencies (InBody720; Biospace Co., CA, USA) in barefoot condition and wearing only underwear, as in our previous study [49]. All anthropometrical parameters of the thigh were measured from the right leg. Thigh length was measured using a tape measure and defined as the distance between the lateral condyle of the femur and the greater trochanter. Thigh circumference was measured using a tape measure at 50% of the thigh length. Anterior and posterior thigh thicknesses of muscle and substantial fat tissues were measured using a B-mode US apparatus (SSD-3500SV; Aloka, Japan) with a 7.5-MHz liner probe at a same location to thigh circumference measurement (i.e., 50% of the thigh length) [50].

2.13. Statistical analysis

Data are presented as the mean ± SD. Changes in cardiovascular (i.e., HR and MAP) and psychological (i.e., affect, task motivation, and perceived pain) parameters throughout experimental session between BFR and NBFR walking were analyzed using a 2 × 7 two-way ANOVA. Changes in RPE and rating of leg discomfort during the two exercise sessions were analyzed using a 2 × 5 tow-way ANOVA. Changes in blood metabolites (i.e., blood glucose and lactate levels) and mood states throughout the two experimental sessions were analyzed using a 2 × 3 two-way ANOVA. As these ANOVA, if the sphericity assumption was not met, Greenhouse-Geisser corrections were used. Specific differences between conditions and time points were identified with a paired Student's *t*-test and Bonferroni post-hoc test, respectively. Comparison of enjoyment immediately after exercise session between the two conditions was compared using a paired Student's *t*-test. The statistical significance level was defined at $P < 0.05$. All statistical analyses were conducted using IBM SPSS software (Ver. 19.0, IBM Corp, NY, USA).

Partial eta squared (η_p^2) values were determined as a measure of the effect size for main effects of condition and time and interaction effect. Cohen's *d* effect size using the pooled SD was calculated to determine the magnitude of difference in measured parameters between conditions [51]. The Cohen's *d* effect size was interpreted as small (0.20–0.49), medium (0.50–0.79) and large (>0.80).

3. Results

3.1. Cardiovascular and blood metabolite responses

Changes in cardiovascular and blood metabolite responses throughout BFR and NBFR walking sessions are presented in Figure 2. Analyses of HR and MAP revealed significant main effects for condition ($F_{(1, 17)} = 46.50$, $P < 0.001$, $\eta_p^2 = 0.73$ and $F_{(1, 17)} = 26.76$, $P < 0.001$, $\eta_p^2 = 0.61$, respectively) and time ($F_{(1.85, 31.38)} = 301.83$, $P < 0.001$, $\eta_p^2 = 0.95$ and $F_{(2.50\ 42.45)} = 27.46$, $P < 0.001$, $\eta_p^2 = 0.62$, respectively) and significant interaction effects ($F_{(1.74, 29.57)} = 35.89$, $P < 0.001$, $\eta_p^2 = 0.68$ and $F_{(2.57, 43.77)} = 23.16$, $P < 0.001$, $\eta_p^2 = 0.58$, respectively). HR significantly increased during BFR and NBFR walking compared with that before walking (all *P*s < 0.001 between time points for each condition). MAP was significantly increased during BFR walking but not during NBFR walking compared with that before exercise (all *P*s < 0.001 between time points). HR and MAP from the first or second, respectively, to last sets during walking were significantly higher with BFR than with NBFR (all *P*s < 0.001 for each parameter), with large effect size (all *d*s = 1.41 to 1.90 and 1.30 to 1.87, respectively, for both protocols). Such a significant difference between conditions was observed for the HR at the 30-min post-exercise recovery period ($P = 0.029$), with small effect size ($d = 0.35$).

Changes in blood metabolite responses throughout BFR and NBFR walking sessions are shown in Table 1. Blood lactate analysis revealed significant main effects for condition ($F_{(1,17)} = 21.84$, $P < 0.001$, $\eta_p^2 = 0.56$) and time ($F_{(1.09, 18.59)} = 28.80$, $P < 0.001$, $\eta_p^2 = 0.59$) and a significant interaction effect ($F_{(1.17, 19.82)} = 26.45$, $P < 0.001$, $\eta_p^2 = 0.61$). Blood lactate significantly increased immediately after BFR walking but not after NBFR walking compared that before exercise ($P < 0.001$), with large effect size ($d = 1.70$). Blood lactate immediately after walking was significantly higher with BFR than with NBFR ($P < 0.001$), with large effect size ($d = 1.73$). Blood glucose analysis revealed a significant main effect for time ($F_{(2, 34)} = 3.87$, $P = 0.031$, $\eta_p^2 = 0.19$) and a significant interaction effect ($F_{(1.34, 22.82)} = 4.60$, $P = 0.033$, $\eta_p^2 = 0.21$); however, there was no significant main effect for condition. Blood glucose significantly decreased 30 min after BFR walking compared with that immediately walking ($P = 0.005$), with large effect size ($d = 1.00$). A trend toward significance was observed with a lower blood glucose 30 min after NBFR walking than before walking ($P = 0.050$), with large effect size ($d = 1.00$).

3.2. RPE and leg discomfort responses

Changes in RPE and leg discomfort during BFR and NBFR walking are shown in Table 2. Analyses of RPE and leg discomfort revealed significant main effects for condition ($F_{(1, 17)} = 101.85$, $P < 0.001$, $\eta_p^2 = 0.86$ and $F_{(1, 17)} = 139.01$, $P < 0.001$, $\eta_p^2 = 0.89$, respectively) and time ($F_{(1.55, 26.41)} = 109.18$, $P < 0.001$, $\eta_p^2 = 0.87$ and $F_{(2.01, 34.11)} = 141.08$, $P < 0.001$, $\eta_p^2 = 0.89$, respectively) and significant interaction effects ($F_{(2.75, 46.74)} = 53.97$, $P < 0.001$, $\eta_p^2 = 0.76$ and $F_{(2.36, 40.17)} = 85.95$, $P < 0.001$, $\eta_p^2 = 0.83$, respectively). RPE and leg discomfort significantly increased during BFR and NBFR walking compared with that before walking (all *P*s < 0.05 between time points for each condition). Levels of RPE and leg discomfort from the first to last sets during walking were significantly higher with BFR than with NBFR (all *P*s < 0.001), with large effect size (all *d*s = 1.56 to 2.66 and 2.59 to 3.53, respectively).

3.3. Affect, task motivation, and perceived pain responses

Changes in perceptual psychological responses throughout BFR and NBFR walking sessions are presented in Figure 3. Affect analysis revealed significant main effects for condition ($F_{(1, 17)} = 19.19$, $P < 0.001$, $\eta_p^2 = 0.53$) and time ($F_{(1.74, 29.56)} = 3.83$, $P = 0.038$, $\eta_p^2 = 0.18$) and a significant interaction effect ($F_{(2.45, 41.72)} = 8.02$, $P = 0.001$, $\eta_p^2 = 0.32$). Medium-sized effect was observed for affect between before and immediately after BFR walking ($d = 0.078$), whereas even small effect size was not observed between before and immediately after NBFR walking, suggesting the existence of decreased affect during BFR walking but not during NBFR walking. Affect levels from the first to last sets during

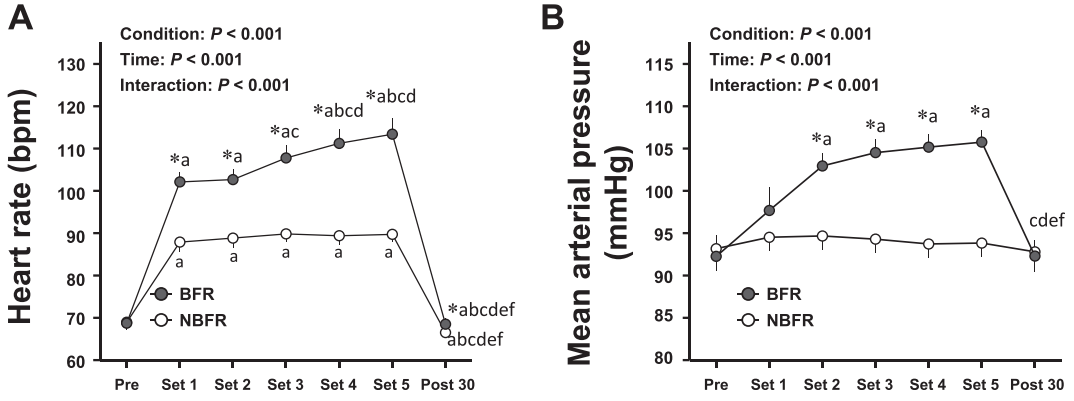

Figure 2. Changes in cardiovascular responses throughout BFR and NBFR walking sessions. (A) Changes in heart rate throughout experimental sessions. (B) Changes in mean arterial pressure throughout experimental sessions. Data are presented as Mean ± SEM. $^{*}P < 0.05$ vs. NBFR, $^{a}P < 0.05$ vs. before walking (i.e., Pre), $^{b}P < 0.05$ vs. 1 set, $^{c}P < 0.05$ vs. 2 set, $^{d}P < 0.05$ vs. 3 set, $^{e}P < 0.05$ vs. 4 set, $^{f}P < 0.05$ vs. 5 set.

Table 1. Changes in blood glucose and lactate levels throughout blood flow restriction (BFR) and non-BFR (NBFR) walking sessions.

	BFR walking			NBFR walking			*P* values		
	Pre	Post	Post 30	Pre	Post	Post 30	Condition	Time	Interaction
Blood lactate, mM	1.0 ± 0.0	1.5 ± 0.1 ^{*a}	1.0 ± 0.0^{b}	1.0 ± 0.0	0.9 ± 0.0	0.9 ± 0.0	**<0.001**	**<0.001**	**<0.001**
Blood glucose, mg/dl	96.4 ± 1.9	99.5 ± 1.4	93.8 ± 1.2^{b}	99.4 ± 1.7	95.4 ± 1.7	94.8 ± 1.0	0.989	**0.031**	**0.033**

Values are presented as Mean ± SEM. Bold *P* value indicates significant main effects of condition and/or time or a significant interaction effect. $^{*}P < 0.05$ vs. NBFR, $^{a}P < 0.05$ vs. before walking (i.e., Pre), $^{b}P < 0.05$ vs. immediately after walking (i.e., Post).

Table 2. Changes in ratings of perceived exertion and leg discomfort during BFR and NBFR walking.

	Time points						*P* values		
	Pre	1 set	2 set	3 set	4 set	5 set	Condition	Time	Interaction
RPE									
BFR walking	6.0 ± 0.0	10.9 ± 0.6 ^{*a}	12.6 ± 0.6 ^{*ab}	13.4 ± 0.6 ^{*abc}	14.3 ± 0.6 ^{*abcd}	14.5 ± 0.6 ^{*abcde}	**<0.001**	**<0.001**	**<0.001**
NBFR walking	6.0 ± 0.0	7.9 ± 0.4^{a}	8.5 ± 0.4^{a}	8.8 ± 0.4 ^{ab}	9.0 ± 0.5 ^{ab}	9.1 ± 0.5 ^{ab}			
Leg discomfort									
BFR walking	0.0 ± 0.0	3.9 ± 0.3 ^{*a}	5.1 ± 0.4 ^{*ab}	5.9 ± 0.4 ^{*abc}	6.6 ± 0.4 ^{*abcd}	7.0 ± 0.5 ^{*abcd}	**<0.001**	**<0.001**	**<0.001**
NBFR walking	0.0 ± 0.0	0.9 ± 0.2	1.0 ± 0.3^{a}	1.2 ± 0.3^{a}	1.2 ± 0.3^{a}	1.3 ± 0.3^{a}			

Values are presented as Mean ± SEM. RPE; rating of perceived exertion. Bold *P* value indicates significant main effects of condition and time or a significant interaction effect. $^{*}P < 0.001$ vs. NBFR, $^{a}P < 0.001$ vs. Pre, $^{b}P < 0.05$ vs. 1 set, $^{c}P < 0.01$ vs. 2 set, $^{d}P < 0.001$ vs. 3 set, $^{e}P < 0.001$ vs. 4 set.

walking were significantly higher with BFR than with NBFR (all *P*s < 0.01), with medium or large effect size (all *d*s = 0.77 to 1.27). Task motivation revealed a significant main effect for condition ($F_{(1, 17)} = 13.78$, $P = 0.002$, $\eta_p^2 = 0.45$) and a significant interaction effect ($F_{(2.69, 45.67)} = 4.73$, $P = 0.008$, $\eta_p^2 = 0.22$). Large-sized effect was observed for task motivation between before and immediately after BFR walking ($d = 0.087$), whereas even small effect size was not observed between before and immediately after NBFR walking, suggesting the existence of decreased task motivation during BFR walking but not during NBFR walking. Task motivation levels from the first to last sets during walking were significantly higher with BFR than with NBFR (all *P*s < 0.05), with medium or large effect size (*d*s = 0.54 to 1.24). Such a significant difference between conditions was remained for task motivation at the 30-min post-exercise recovery period ($P = 0.001$), with medium effect size ($d = 0.63$). Perceived pain revealed significant main effects for condition ($F_{(1, 17)} = 214.54$, $P < 0.001$, $\eta_p^2 = 0.93$) and time ($F_{(2.14, 36.38)} = 245.07$, $P < 0.001$, $\eta_p^2 = 0.92$) and a significant interaction effect ($F_{(2.16, 36.66)} = 109.92$, $P < 0.001$, $\eta_p^2 = 0.87$). Perceived pain significantly increased during BFR walking but not during NBFR walking compared with that before walking (all *P*s < 0.05). Perceived pain levels from the first to last sets during walking were significantly higher with BFR than with NBFR (all *P*s < 0.001), with large effect size (*d*s = 3.39 to 4.97).

3.4. Mood states and enjoyment

Changes in total mood disturbance and mood states throughout BFR and NBFR walking sessions are shown in Table 3. Total mood disturbance revealed a significant interaction effect ($F_{(1.43, 24.30)} = 5.01$, $P = 0.024$, $\eta_p^2 = 0.23$); however there were no significant main effects for condition and time. Total mood disturbance throughout experimental session did not differ significantly between time points or conditions. In six mood profiles, tension-anxiety analysis revealed a significant main effect for time ($F_{(1.46, 24.78)} = 7.65$, $P = 0.005$, $\eta_p^2 = 0.31$) and a significant interaction effect ($F_{(2, 34)} = 6.77$, $P = 0.003$, $\eta_p^2 = 0.28$). Confusion-bewilderment analysis revealed a significant main effect for time ($F_{(1.31, 22.33)} = 4.23$, $P = 0.032$, $\eta_p^2 = 0.20$), and a trend toward such a significant effect was observed for an interaction effect ($F_{(2, 34)} = 3.13$, $P = 0.056$, $\eta_p^2 = 0.16$). Fatigue-inertia analysis revealed a significant interaction effect ($F_{(2, 34)} = 3.38$, $P = 0.046$, $\eta_p^2 = 0.17$). A trend toward significance effect was observed for a main time effect of vigor-activity ($F_{(2, 34)} = 3.00$, $P = 0.063$, $\eta_p^2 = 0.15$). Although these mood profiles throughout experimental session did not differ significantly between time points or conditions, a trend toward significance was observed with a higher fatigue-inertia immediately after BFR walking than that immediately after NBFR walking ($P = 0.065$), with small effect size ($d = 0.047$).

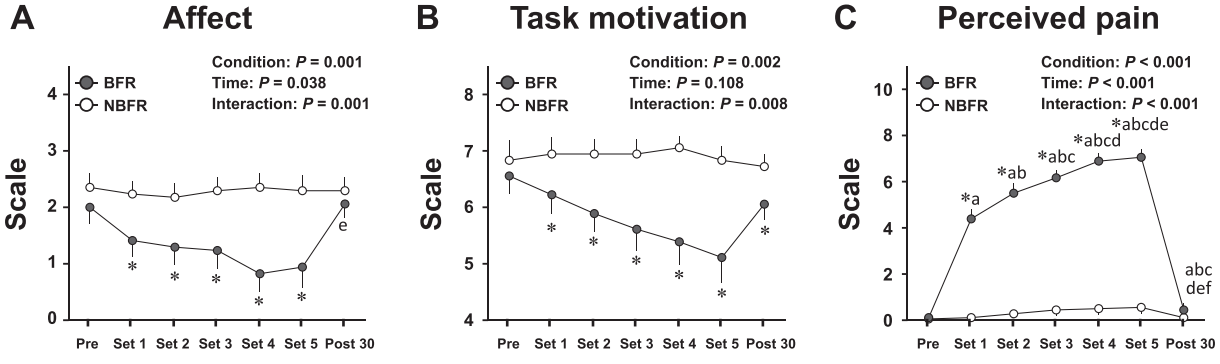

Figure 3. Changes in perceptual psychological responses throughout BFR and NBFR walking sessions. (A) Changes in the FS-measured affect throughout experimental sessions. (B) Changes in the TMS-measured task motivation throughout experimental sessions. (C) Changes in the NRS-measured perceived pain throughout experimental sessions. Data are presented as Mean ± SEM. $^{*}P < 0.05$ vs. NBFR, $^{a}P < 0.05$ vs. Pre, $^{b}P < 0.05$ vs. 1 set, $^{c}P < 0.05$ vs. 2 set, $^{d}P < 0.05$ vs. 3 set, $^{e}P < 0.05$ vs. 4 set, $^{f}P < 0.05$ vs. 5 set.

Table 3. Changes in total mood disturbance and mood states throughout BFR and NBFR walking sessions.

	BFR walking			NBFR walking			*P* values		
	Pre	Post	Post 30	Pre	Post	Post 30	Condition	Time	Interaction
Total mood disturbance	7.4 ± 3.1	9.6 ± 3.9	6.9 ± 3.6	11.2 ± 3.7	5.8 ± 3.7	6.8 ± 3.7	0.994	0.121	**0.024**
Anger-hostility	1.6 ± 0.4	2.1 ± 0.6	1.7 ± 0.5	1.9 ± 0.6	1.4 ± 0.3	1.1 ± 0.4	0.574	0.262	0.125
Confusion-bewilderment	4.4 ± 0.8	4.5 ± 0.9	4.1 ± 0.8	5.4 ± 0.8	4.2 ± 0.8	4.1 ± 0.8[a]	0.665	**0.042**	0.056
Depression-dejection	2.4 ± 0.5	2.4 ± 0.5	1.9 ± 0.5	2.6 ± 0.5	1.9 ± 0.5	2.2 ± 0.6	0.968	0.094	0.244
Fatigue-inertia	5.0 ± 0.8	6.7 ± 1.0	5.4 ± 0.9	5.5 ± 0.8	4.8 ± 1.0	5.3 ± 0.9	0.374	0.663	**0.046**
Tension-anxiety	4.9 ± 0.9	4.6 ± 0.9	4.1 ± 0.9	6.8 ± 1.0	4.5 ± 1.1[a]	4.4 ± 1.0[a]	0.452	**0.005**	**0.003**
Vigor-activity	11.0 ± 1.1	10.7 ± 1.3	10.3 ± 1.2	11.0 ± 1.2	11.0 ± 1.2	10.3 ± 1.2	0.901	0.063	0.524

Values are presented as Mean ± SEM. Bold *P* value indicates a significant main effect of time or a significant interaction effect. [a]$P < 0.05$ vs. Pre.

Comparison of enjoyment after BFR and NBFR walking sessions is shown in Figure 4. Enjoyment immediately after walking was significantly lower with BFR than with NBFR ($P = 0.002$), with small effect size ($d = 0.42$).

3.5. Relationships of anthropometric parameters and physiological responses with perceptual responses during BFR walking

Mean values of anthropometric parameters in subjects were 173.9 ± 1.1 (range, 167.0 to 183.1) cm for body height, 61.5 ± 1.4 (range, 51.4 to 70.9) kg for body weight, 50.4 ± 0.9 (range, 53.3 to 56.4) kg for whole-body skeletal muscle mass, 8.1 ± 0.8 (range, 3.6 ± 18.2) kg for whole body fat mass, 40.6 ± 0.3 (range, 38.0 to 43.2) cm for thigh length, 49.9 ± 0.7 (range, 45.4 to 55.3) cm for thigh circumference, 52.2 ± 1.6 (range, 3.84 to 6.52) mm for anterior thigh muscle thickness, 61.7 ± 1.2 (range, 52.8 to 70.7) mm for posterior thigh muscle thickness, 3.8 ± 0.4 (range, 1.4 to 7.4) mm for anterior thigh subcutaneous fat thickness, and 4.7 ± 0.6 (range, 1.6 to 10.0) mm for posterior thigh subcutaneous fat thickness.

Correlation coefficients of anthropometric parameters and physiological responses with perceptual responses are shown in Table 4. With regard to relationship between anthropometric parameters and perceptual responses during BFR walking, larger anterior thigh muscle thickness correlated significantly with greater leg discomfort response (i.e., a difference between before and immediately after walking, ΔCR-10; $r = -0.490$, $P = 0.039$). A trend toward such significant correlation was observed between anterior thigh MT and RPE response (ΔRPE; $r = -0.424$, $P = 0.079$). Larger posterior thigh subcutaneous fat thickness correlated significantly with greater RPE response ($r = -0.502$, $P = 0.034$). With regard to relationship between physiological and perceptual responses, there was a significant correlation between HR and TMD responses ($r = 0.669$, $P = 0.002$). A trend toward such significant correlation was observed between HR response and PACES ($r = -0.424$, $P = 0.079$). Additionally, there was a significant correlation between blood lactate and leg discomfort responses ($r = 0.566$, $P = 0.014$). A trend toward such significant correlation was observed between blood lactate and perceived pain responses (ΔNRS; $r = -0.454$, $P = 0.058$).

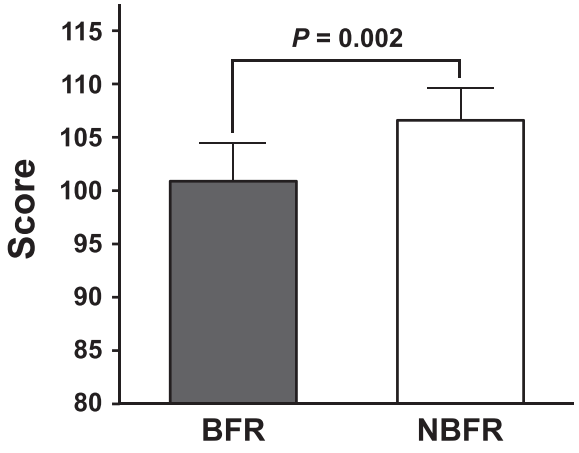

Figure 4. Comparison of enjoyment immediately after BFR and NBFR walking. Data are presented as Mean ± SEM. Enjoyment was measured using the PACES.

4. Discussion

Previous studies reported that increases in RPE and leg discomfort during both modes of resistance and aerobic cycling exercises were greater with BFR than with NBFR [13, 14, 15, 19, 21]. Moreover, in both exercise modes, increases in these perceived exertion parameters induced by low-intensity exercise with BFR are similar to or higher than that induced by high-intensity exercise [13, 14, 15, 19]. Furthermore, several previous studies demonstrated that an increase in RPE during walking is greater with BFR than with NBFR [12, 16, 17]. In the present study, RPE and leg discomfort measured using the Borg's 15 point and Category-Ratio Scales were significantly higher during BFR walking than during NBFR walking. This finding corroborates the results of the previous studies [12, 16, 17]. Therefore, although it is a mild exercise mode, perceived exertion responses are more elevated during BFR walking than during NBFR walking, according to the results of resistance and aerobic exercises [13, 14, 15, 19, 21].

Prior to this study, no study has examined the effect of BFR exercise on important perceptual psychological parameters (e.g., affect and task motivation) related to exercise adherence. Many previous studies reported that affect and task motivation decreased during some protocols of resistance and aerobic exercises [24, 33, 47, 48, 52, 53, 54]. For example, previous studies determined that aerobic exercise-induced decreases in affect and task motivation are observed in exercise-intensities higher than ventilation threshold [53, 54]. Moreover, previous studies reported that affect and task motivation were lower during vigorous interval exercise, including high-intensity/sprint interval exercise, than during moderate-intensity continuous exercise [24, 47, 48]. These findings suggest that the magnitude of negative perceptual responses based on affect and task motivation may be dependent on exercise-intensity. In the present study, we found that FS-measured affect and the TMS-measured task motivation decreased during BFR walking but not during NBFR walking compared with that before walking, with medium and large effect sizes, respectively, and these parameters were significantly lower during BFR walking than during NBFR walking. Additionally, we examined changes in the NRS-measured pain throughout the experimental session. In this result, the perceived pain was significantly and gradually increased during BFR walking, but not NBFR walking, and this parameter throughout walking session were significantly higher for BFR walking than for NBFR walking. The increase in perceived pain induced by BFR walking appears to be mainly due to mechanical pain related to the imposed BFR pressure [34, 35]. The BFR-induced increase in perceived pain during walking may be the basis of negative responses of other perceptual physiopsycological (i.e., RPE and leg discomfort) and

Table 4. Correlation coefficients of anthropometric parameters and physiological responses with perceptual responses to BFR walking.

	ΔRPE	ΔCR-10	ΔFS	ΔTMS	ΔNRS	ΔTMD	PACES
Body height	−0.248 ($P = 0.321$)	0.058 ($P = 0.821$)	0.185 ($P = 0.462$)	0.345 ($P = 0.161$)	−0.237 ($P = 0.344$)	−0.198 ($P = 0.432$)	0.149 ($P = 0.556$)
Body weight	−0.272 ($P = 0.274$)	−0.281 ($P = 0.259$)	−0.002 ($P = 0.993$)	0.372 ($P = 0.128$)	−0.184 ($P = 0.486$)	−0.207 ($P = 0.409$)	0.219 ($P = 0.382$)
Whole body SKM	−0.105 ($P = 0.677$)	−0.205 ($P = 0.414$)	0.029 ($P = 0.908$)	0.420 ($P = 0.082$)	−0.141 ($P = 0.576$)	−0.159 ($P = 0.529$)	0.337 ($P = 0.171$)
Whole body FM	−0.334 ($P = 0.176$)	−0.216 ($P = 0.390$)	−0.057 ($P = 0.822$)	0.105 ($P = 0.679$)	−0.139 ($P = 0.581$)	−0.163 ($P = 0.519$)	−0.056 ($P = 0.825$)
Thigh length	−0.290 ($P = 0.242$)	−0.013 ($P = 0.961$)	0.018 ($P = 0.944$)	0.297 ($P = 0.232$)	−0.399 ($P = 0.101$)	−0.247 ($P = 0.324$)	0.057 ($P = 0.823$)
Thigh circumference	−0.129 ($P = 0.611$)	−0.310 ($P = 0.211$)	−0.082 ($P = 0.745$)	0.290 ($P = 0.244$)	0.014 ($P = 0.957$)	−0.039 ($P = 0.879$)	0.196 ($P = 0.477$)
Anterior thigh MT	−0.424 ($P = 0.079$)	**−0.490 ($P = 0.039$)**	−0.026 ($P = 0.920$)	0.240 ($P = 0.337$)	−0.398 ($P = 0.102$)	0.031 ($P = 0.902$)	0.155 ($P = 0.539$)
Posterior thigh MT	−0.360 ($P = 0.142$)	−0.190 ($P = 0.451$)	0.012 ($P = 0.962$)	0.395 ($P = 0.105$)	−0.037 ($P = 0.885$)	0.096 ($P = 0.705$)	−0.024 ($P = 0.926$)
Anterior thigh SFT	−0.264 ($P = 0.291$)	0.170 ($P = 0.501$)	−0.179 ($P = 0.477$)	−0.015 ($P = 0.954$)	0.128 ($P = 0.613$)	−0.022 ($P = 0.931$)	−0.098 ($P = 0.700$)
Posterior thigh SFT	**−0.502 ($P = 0.034$)**	−0.190 ($P = 0.451$)	−0.080 ($P = 0.751$)	0.099 ($P = 0.695$)	−0.299 ($P = 0.228$)	0.128 ($P = 0.612$)	−0.218 ($P = 0.386$)
ΔHR	0.117 ($P = 0.644$)	0.094 ($P = 0.712$)	−0.097 ($P = 0.702$)	−0.288 ($P = 0.247$)	0.382 ($P = 0.118$)	**0.669 ($P = 0.002$)**	−0.443 ($P = 0.066$)
ΔMAP	0.249 ($P = 0.318$)	−0.232 ($P = 0.355$)	0.066 ($P = 0.795$)	−0.348 ($P = 0.157$)	−0.162 ($P = 0.521$)	−0.043 ($P = 0.864$)	−0.007 ($P = 0.978$)
ΔBlood lactate	0.177 ($P = 0.482$)	**0.566 ($P = 0.014$)**	−0.106 ($P = 0.675$)	−0.034 ($P = 0.894$)	0.454 ($P = 0.058$)	0.276 ($P = 0.267$)	−0.317 ($P = 0.201$)
ΔBlood glucose	−0.161 ($P = 0.524$)	−0.376 ($P = 0.124$)	−0.107 ($P = 0.674$)	−0.353 ($P = 0.150$)	−0.390 ($P = 0.110$)	0.060 ($P = 0.813$)	−0.149 ($P = 0.555$)

Perceptual and physiological responses were defined as pre-post difference (i.e., Δ) induced by BFR walking. CR-10; Borg's Category-Ratio Scale (measuring leg discomfort), FS; Feeling Scale (measuring affect), TMS; Task Motivation Scale (measuring task motivation), NRS; Numerical Rating Scale (measuring perceived pain), TMD; Profile of Mood States-measured total mood disturbance, PACES; Physical Activity Enjoyment Scale (measuring enjoyment). SKM; skeletal muscle mass, FM; fat mass, MT; muscle thickness, SFT; subcutaneous fat thickness. HR; heart rate, MAP; mean arterial pressure. Bold fonts indicate significant correlations ($P < 0.05$) of anthropometric parameters or physiological responses with perceptual responses.

psychological (i.e., affect and task motivation) parameters, potentially by increasing unpleasant sensation [55]. This may attribute to changing some neural systems, especially group III sensory neurons largely associated with the mechanoreflex [56]. The present study is the first to determine the negative effects of BFR exercise on perceptual psychological parameters with similarities to perceptual physiopsycological parameters.

A couple of studies by Silva et al. [18, 20] reported the negative effects of BFR on changes in mood statuses induced by resistance and aerobic exercises. One of their studies found, using low-intensity resistance exercise, that BFR induced negative responses of some mood profiles, measured using the Brunel Mood Scale [18]. In another study, they also determined that the Brunel Mood Scale-measured total mood disturbance immediately after low-intensity aerobic exercise was greater with BFR than with NBFR [20]. Their findings suggest that BFR induces negative mood statuses during both resistance and aerobic exercises. By contrast, in the present study, the POMS-measured total mood disturbance was not significantly increased by both BFR and NBFR walking, and this parameter immediately after walking session did not differ between the two conditions. This disagreement between the findings of the present and previous studies may be due to a difference in magnitude of exercise-induced HR response among exercise modes (i.e., walking vs. slow running and resistance exercise), based on a significant correlation between changes in HR and total mood disturbance before and after BFR walking obtained in the present study. In contrast to the total mood disturbance, a trend against significance was observed between the fatigue-inertia profiles immediately after BFR and NBFR walking. This finding suggests that BFR may slightly induce negative response of mood profile to walking.

Enjoyment can be considered the most important perceptual parameter related to exercise adherence [2, 3, 42]. Some previous studies determined that enjoyment was higher after high-intensity interval exercise than after moderate-intensity continuous exercise [44, 48], despite greater negative responses of the other aforementioned perceptual parameters during high-intensity interval exercise than those during moderate-intensity continuous exercise [24, 44, 47, 48]. Nevertheless, other studies reported that the enjoyment after high-intensity interval exercise is similar to or higher than that after moderate-intensity continuous exercise [24, 47]. Thus, whether enjoyment, similar to other perceptual parameters, would be dependent on exercise intensity is inconsistent among the findings of the previous studies [24, 44, 47, 48]. In the present study, the PACES-measured enjoyment immediately after walking was significantly lower with BFR than with NBFR; therefore, the former may decrease adherence to this exercise on the part of some individuals. The present study is also the first to determine the negative effect of BFR exercise on enjoyment.

This study determined that cardiovascular responses such as HR and MAP were significantly greater during BFR walking than during NBFR walking. In particular, because the close relationship between HR and perceived exertion responses during exercise is well known [27, 29], greater RPE and leg discomfort for BFR walking than those for NBFR walking may be due to the difference in HR response between the two conditions. Furthermore, previous studies determined an inverse correlation between changes in FS-measured affect and RPE during exercise [30, 31]; thus, affective response during exercise may be mediated by HR and/or perceived exertion responses. Therefore, the results of cardiovascular responses, especially HR, during BFR walking may contribute to explain its negative effect on perceived exertion and affective responses.

Changes in exercise-induced perceptual parameters may be associated with metabolite responses, in addition to cardiovascular responses, such as increased by-products in blood and skeletal muscle [21, 27, 29]. In the present study, blood lactate was significantly, but slightly, increased by BFR walking, but not NBFR walking, and this level immediately after walking was significantly higher with BFR than with NBFR. Moreover, there was a significant correlation between changes in blood lactate and leg discomfort before and immediately after BFR walking. Additionally, we previously reported that changes in intramuscular metabolites (e.g., creatine phosphate depletion, increased inorganic phosphate, and decrease intracellular pH), assessed using a phosphorus magnetic resonance spectroscopy, during low-intensity resistance exercise was greater with BFR than with NBFR [21]. The increased intramuscular metabolic stress of the exercising muscles during the BFR exercise is in parallel with elevated leg discomfort [21]. Therefore, the negative effects of BFR on perceptual response to walking may be associated with increased blood lactate levels and intramuscular metabolic stress, which may bring about enhanced local and central sensations [57].

Previous studies reported that listening to music reduces the negative effect (e.g., increased perceived exertion and decreased affect) on perceptual parameters induced by aerobic exercise [33, 58]. Of those, we demonstrated that an increase in RPE during aerobic exercise with music was lower than that without music [58]. Furthermore, previous studies

determined that in addition to music, watching the video reduces negative responses on perceptual parameters induced by aerobic exercise, and a combination of music and video reduces the negative effect additively [45, 46]. These findings suggest that music and/or video during BFR walking may attenuate the negative effects on perceptual parameters.

This study has some limitations. Notably, we employed an absolute BFR pressure of 200 mmHg for performing BFR walking, as in previous studies [9, 10, 16, 17]. However, recent reviews have recommended the use of the relative BFR pressure based on the individual's arterial occlusion pressure [6, 7]. Thus, the absolute pressure of 200 mmHg during BFR walking employed in the present study may be high compared to the relative BFR pressure. This higher BFR pressure might exacerbate perceptual response during BFR walking. Indeed, the difference in BFR pressure applied during low-load BFR resistance exercise affects the magnitude of its perceptual responses [13, 14], potentially by increasing by-products in blood and skeletal muscle [21]. Furthermore, Clarkson et al. [12] reported that RPE during BFR walking with a relative BFR pressure (i.e., mean, 134 mmHg) of 60% arterial occlusion pressure in older individuals was 14, which was lower than that during BFR walking with the absolute BFR pressure in young individuals observed in the present study. Thus, an application of low BFR pressures for BFR walking can mitigate perceptual responses during this walking, but it may reduce muscle adaptations induced by long-term training [8]. Furthermore, we employed 10-cm cuffs for performing BFR walking and determined that muscle and subcutaneous fat thicknesses of the thigh correlated with differences in RPE and leg discomfort between before and after BFR walking. In a study by Loenneke et al. [15], the individual's BFR pressure of the knee extensor low-intensity resistance exercise was provided using differing sizes of occlusion cuffs based on the participant's thigh circumference. These findings suggest that pressure and cuff size used during BFR exercise need to be determined from the individual's arterial occlusion pressure and limb morphology. Further studies are needed to determine the effects of various pressures and cuff sizes employing BFR walking on perceptual responses.

As another limitation, although we determined that a single session of BFR walking induced negative effects on perceptual responses, previous studies reported that long-term intervention (i.e., repeated sessions) of low-load BFR resistance exercise mitigated perceived exertion responses during this exercise throughout the training period [59, 60]. Furthermore, Clarkson et al. [12] determined that RPE response during BFR walking diminished throughout a 6-weeks training period (i.e., 14 vs. 11, respectively, at baseline and 6 week). This may be due to increased tolerance to BFR, which may attribute to pain modulation related to hypoalgesia and endogenous opioid [14]. These findings suggest that acute negative responses, especially elevated perceived exertion, induced by BFR walking can be minimized according with increased duration of long-term intervention. Despite this, whether long-term BFR exercise can mitigate elevations in some perceptual responses, especially those related to exercise adherence, remains unknown. Further studies are needed to determine the mitigation effects of long-term BFR exercise, including walking, on these perceptual responses.

In the current study, we determined that perceptual responses, including major perceptual parameters related to exercise adherence, were greater for BFR walking than for NBFR walking. This is considered a barrier to exercise participation of some individuals. Skeletal muscle weakness (e.g., decreased muscle mass and strength) and exercise intolerance (e.g., decreased exercise endurance and maximal oxygen consumption) are prominent factors that indicate poor prognosis in older individuals and patients with chronic diseases [61, 62]. Thus, the BFR exercise is preferentially required for these populations. Indeed, BFR exercises, including walking, remarkably and effectively improve both skeletal muscle weakness and exercise intolerance in older individuals [4]. Furthermore, several previous studies reported beneficial effects of BFR exercises on improvements in skeletal muscle weakness and exercise intolerance in patients with chronic heart failure [63, 64]. Therefore, to further popularize BFR exercise in the clinical setting, there is a need to develop effective strategies against the BFR-induced negative effects on perceptual response during exercise, which may be useful in improving adherence to the BFR exercise in various populations, including in older individuals and patients with chronic diseases.

5. Conclusion

This study demonstrated that perceptual responses during walking were greater with BFR than with NBFR. These findings suggest that BFR may have negative effects on perceptual responses to walking in healthy young adults.

Declarations

Author contribution statement

E. Mok and T. Suga: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

T. Sugimoto, K. Tomoo and K. Dora: Performed the experiments; Analyzed and interpreted the data.

S. Takada, T. Hashimoto and T. Isaka: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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