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Research article

Effect of High-Intensity Interval Exercise versus Continuous Low-Intensity Aerobic Exercise with Blood Flow Restriction on Psychophysiological Responses: A Randomized Crossover Study

Victor S. de Queiros [1]✉, Nicholas Rolnick [2], Angelo Sabag [3], Phelipe Wilde [1], Thiago Peçanha [4], Rodrigo Ramalho Aniceto [5], Roberto Felipe Câmara Rocha [6], Douglas Z. Delgado [7], Breno Guilherme de Araújo Tinôco Cabral [7] and Paulo Moreira Silva Dantas [1,7]

[1] Graduate Program in Health Sciences, Federal University of Rio Grande do Norte (UFRN), Natal-RN, Brazil; [2] The Human Performance Mechanic, CUNY Lehman College, New York, USA; [3] Discipline of Exercise and Sport Science, Faculty of Medicine and Health, The University of Sydney, Sydney, Australia; [4] Department of Sport and Exercise Sciences, Manchester Metropolitan University Institute of Sport, Manchester Metropolitan University, Manchester, UK; [5] Study and Research Group in Biomechanics and Psychophysiology of Exercise, Federal Institute of Education, Science and Technology of Rio Grande do Norte, Currais Novos-RN, Brazil; [6] Department of Physical Education, Federal University of Rio Grande do Norte (UFRN), Natal-RN, Brazil; [7] Graduate Program in Physical Education, Federal University of Rio Grande do Norte (UFRN), Natal-RN, Brazil

Abstract

This study compared the effect of continuous low-intensity aerobic exercise with blood flow restriction (LI-AE-BFR) versus high-intensity interval exercise (HIIE), matching total external mechanical work between conditions, on perceptual (exertion, pain, affective and pleasure) and physiological responses (heart rate [HR], blood lactate [BL] and muscle fatigue). Ten healthy untrained men (25.6 ± 3.78 years old; 75.02 ± 12.02 kg; 172.2 ± 6.76 cm; 24.95 ± 3.16 kg/m²) completed three visits to the laboratory. In visit 1, anthropometry, blood pressure and peak running velocity on the treadmill were measured. In visits 2 and 3, participants were randomly assigned to HIIE or LI-AE-BFR, both in treadmill. HIIE consisted of 10 one-minute stimuli at 80% of peak running velocity interspersed with one-minute of passive recovery. LI-AE-BFR consisted of 20-minutes of continuous walking at 40% of peak running velocity with bilateral cuffs inflated to 50% of arterial occlusion pressure. BL and maximum isometric voluntary contraction (MIVC - fatigue measure) were measured pre- and immediately post-exercise. HR, rating of perceived exertion (RPE), and rating of perceived pain (RPP) were recorded after each stimulus in HIIE and every two minutes in LI-AE-BFR. Affective response to the session, pleasure, and future intention to exercise (FIE) were assessed 10 minutes after the intervention ended. Increases in BL concentrations were greater in HIIE ($p = 0.028$; $r = 0.51$). No effects time or condition were reported for MIVC. HR was higher in HIIE at all analyzed time points ($p < 0.001$; d = 3.1 to 5.2). RPE did not differ between conditions ($p > 0.05$), while average session RPP was higher in LI-AE-BFR ($p = 0.036$; $r = 0.46$). Affective positive response ($p = 0.019$; d = 0.9) and FIE ($p = 0.013$; d = 0.97) were significantly higher in HIIE. Therefore, HIIE elicited higher physiological stress, positive affective response, and intention to engage in future exercise bouts compared to LI-AE-BFR.

Key words: Blood Flow Restriction Therapy; Physical Exertion; Affect; Endurance Training.

Introduction

High-intensity interval exercise (HIIE) is characterized by performing brief high-intensity stimuli interspersed with periods of passive or active recovery (Gibala et al., 2012). Training programs based on this exercise model have the capacity to generate significant adaptations relevant to health (e.g., increased mitochondrial capacity of skeletal muscle) in relatively short training sessions (e.g., 20 minutes) (Little et al., 2010), and therefore could be considered a time-efficient health-enhancing strategy. This aspect is of particular interest as lack of time is seen as a barrier to practicing physical activity (Kimm et al., 2006). On the other hand, it is necessary to consider that high-intensity exercise can elicit negative affective responses (Ekkekakis, 2003). The affective response can be described as the feeling experienced when performing a behavior (e.g., physical exercise). During exercise, this response can be monitored using a bipolar scale, ranging from -5 (very bad) to +5 (very good) (Stevens et al., 2020). Negative affective responses may reduce the chance of future involvement in physical activity programs (Ekkekakis et al., 2011).

According to the Dual Mode Theory, affective valence during physical exercise is modulated by two factors: (i) cognitive parameters (e.g., self-efficacy and attitudes) and (ii) interoceptive signals (e.g., pain, temperature and cortical oxygenation) (Ekkekakis, 2003). At higher intensities, interoceptive signals are dominant and can generate substantial sensations of displeasure. In this sense, alternative training strategies capable of generating relevant physiological adaptations with lower intensities and lower time commitments become relevant.

Blood flow restriction (BFR) training has been suggested as an alternative to high-intensity aerobic training (Silva et al., 2019). BFR training is a physical training technique that typically combines low-intensity exercise with limb BFR using inflatable cuffs (or elastic bands). BFR training has shown to mimic the effects of high-intensity exercise and enables relevant physiological adaptations (e.g., muscle hypertrophy and increased aerobic capacity) in a variety of populations (Patterson et al., 2019) with training sessions usually lasting less than 20 minutes (Park

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et al., 2010; Abe et al., 2010). For example, low-intensity aerobic training with BFR (LI-AE-BFR) can increase maximal aerobic capacity (VO_{2max}) in athletic populations (Park et al., 2010), and increase strength and muscle hypertrophy in young and old people (Abe et al., 2006; Abe et al., 2010).

Although LI-AE-BFR can produce positive adaptations similar to high-intensity training, there is the potential to produce divergent affective responses (Mok et al., 2020). BFR application reduces venous return, eliciting metabolite accumulation that can increase pain perception through afferent stimulation (Rolnick et al., 2021). Furthermore, the accumulation of metabolites likely maximize muscle fatigue, increasing exertion through increased corollary discharge (Morree and Marcora, 2015). In part, the increased perceptual demands may elicit negative affective responses in BFR exercise (Mok et al., 2020; Suga et al., 2021).

Currently, only one paper has investigated the affective response to LI-AE-BFR. Mok et al. (2020) analyzed affection and pleasure following a walking session (5km/hour) with- and without- BFR and identified reduced pleasure and affect in the BFR condition. This finding indicates that BFR may generate inferior affective responses when compared with non-BFR low-intensity exercise; however, no previous study has compared the affective responses between LI-AE-BFR and HIIE. This comparison is of particular interest as high-intensity exercise is typically related to negative affective responses. Additionally, LI-AE-BFR has been suggested as an alternative approach to high-intensity training (Silva et al., 2019).

Therefore, the present study aimed to compare perceptual responses related to adherence in continuous LI-AE-BFR versus HIIE. We opted for a work-matched design with external work (duration x intensity), with the aim of reducing the impact of external intensities on the results presented. Considering that perceptual responses can be affected by physiological variables and that adaptations after training with BFR may be related to fatigue (Jessee et al., 2018) and enhanced physiological stress (Smith et al., 2021), this study also performed comparisons between continuous LI-AE-BFR versus HIIE on acute post-exercise strength decline (measure of fatigue), and lactate and heart rate (HR) changes.

Methods

Participants

Ten untrained men, selected in an intentional non-probabilistic way, participated in this study (See Table 1). Participants were recruited through advertisement in social networks and email, and via word of mouth. The volunteers contacted our research team and were interviewed, aiming to identify whether they met the established eligibility criteria. Men aged 18 - 34 years without cardiovascular or metabolic diseases who had not been participating in any physical training program in the last 6 months were considered eligible. To determine the sample size necessary for this study, we performed an a priori sample calculation considering an effect size of 0.9 for affective response reported in a comparison of LI-AE with versus without BFR in this variable (Mok et al., 2020), an α of 0.05 and a β of 0.2 (80% power). The calculated necessary number was ten individuals. Furthermore, we performed a post hoc sample calculation, considering the effect size reported in our study (0.92) and an α of 0.05. A power of 0.85 was observed. G*Power software (Version 3.1.9.7) was used for these purposes. The calculations followed the recommendations of Beck (2013) and Faul et al. (2007).

Table 1. Participant characteristics.

N = 10	Mean (SD)
Age	25.6 (3.78)
Body mass (kg)	75.02 (12.02)
Height (cm)	172.2 (6.76)
BMI (kg/m²)	24.95 (3.16)
%BF	26.91 (4.98)
SBP (mmHg)	121.9 (7.85)
DBP (mmHg)	71.2 (7.79)
AOP-RIGHT (mmHg)	183.2 (12.67)
AOP-LEFT (mmHg)	177.1 (12.56)
HR peak (bpm)	195.20 (4.42)

AOP, Arterial occlusion pressure, BF, body fat, BMI, body mass index, DBP, diastolic blood pressure, HR, heart rate, SD, standard deviation, SBP, systolic blood pressure.

Participants were excluded if they had contraindications to exercise according to the Physical Activity Readiness Questionnaire (PAR-Q), a resting blood pressure greater than 139/89 mmHg or body mass index (BMI) ≥30 kg/m^2 (Nascimento et al., 2022). The Research Ethics Committee of the Federal University of Rio Grande do Norte (UFRN) approved the study protocol (6.228.202) and participants signed an informed consent form declaring their agreement to participate in the research.

Experimental approach to the problem

This study used an unblinded randomized crossover design to test the effect of continuous LI-AE-BFR versus HIIE on psychophysiological responses. The order of interventions was randomized prior to baseline assessments (after enrollment) using a free online web service for creating random lists (Randomization.com). Each participant made three visits to the laboratory at the same time of day (within-subjects) to minimize diurnal variations in bodily responses. The visits were scheduled according to the participant's availability and were interspersed with a minimum washout of 72 hours. The majority (n = 7) of participants completed three visits with a seven-day washout. For personal reasons, two participants completed the experimental interventions (visit 1 and 2) with a 15-day washout and one participant completed the experimental interventions with a 72-hour washout. Eight participants visited during the morning (8:00 to 10:30), while two participants visited during the afternoon (12:00 to 14:00). Data collections were performed individually. The laboratory temperature was maintained at 21 - 24º during all visits. At visit 1, each participant underwent a maximum effort test to determine peak running speed (V_{peak}) on a treadmill, parameter used to determine the intensity of the exercise sessions performed at visits 2 and 3 (40% and 80% V_{peak} for continuous LI-AE-BFR and HIIE, respectively). Additionally, visit 1 was used to measure brachial blood pressure (bBP), lower limb arterial occlusion pressure (AOP), obtain anthropometric measurements, and body composition (fat percentage and fat-free mass), and familiarization with the scales used in present study. During experimental interventions carried out in visits 2 and 3, HR, rating of perceived exertion (RPE) and rating of perceived pain (RPP) were continuously monitored. Capillary lactate concentration and maximum isometric voluntary contraction (MIVC) of the knee extensors were measured before and immediately after the end of each session. Future intention to exercise (FIE), affective response and enjoyment during exercise was assessed 10 minutes after the end of each training session (Figure 1). Participants were asked to abstain from physical exercise, alcohol, and caffeine (supplements, coffee, chocolates, teas, soft drinks) consumption for 24 hours prior to each visit.

Procedures

Sample characterization

Initially, participants answered an anamnesis with personal and clinical information and a PAR-Q. Then, body mass (kg) and height (cm) were measured. BMI was calculated using the formula: body mass (kg) / height (m)². Body composition (fat percentage and fat-free mass) was assessed by the indirect method of Dual Energy X-Ray Absorptiometry (DEXA) with the GE Healthcare® Lunar Prodigy Advance system from Madison, USA.

Arterial occlusion pressure and blood pressure

Participants were kept at rest for 5 minutes (supine position) to assess bBP and AOP of the lower limbs, in that order. AOP was used to individualize the pressure prescribed in continuous LI-AE-BFR (50% AOP). To obtain AOP, the participant remained standing (position adopted in the exercise) and a cuff was fixed to the proximal region of the thigh while the probe of a portable vascular Doppler (DV2001; Medpej, São Paulo, Brazil) was positioned above the posterior tibial artery to identify the arterial pulse. The cuff was inflated until the arterial pulse disappeared (Gualano et al., 2010). The measurement was carried out in both segments, considering the possibility of significant differences between members (de Queiros, 2023). bBP was determined in the left arm using the oscillometric method (Omron® HEM7200, Omron, USA) following current guidelines (Barroso et al., 2021).

Incremental aerobic testing protocol

The participants performed an incremental exercise test on a treadmill (RT350, Movement, Brazil). The test started at a speed of 5 km/h for 3 minutes. Then, the speed was increased by 1km/h every minute until volitional fatigue. The treadmill incline was kept at 1% during the whole protocol. HR (measured using a chest heart rate monitor, Polar H10) and RPE were recorded in the final 10 seconds of each stage. The peak HR was recorded for posterior analysis and the RPE was used for subsequent anchoring. V_{peak} was the speed corresponding to the speed (km/h) of the last minute completed during the incremental test. We used V_{peak} to personalize the intensity of experimental interventions, as this parameter has greater ecological validity and appears to have good reliability regardless of the training level of the sample investigated (Sá Filho et al., 2018).

Experimental sessions

Experimental sessions were carried out on visits 2 and 3. The workload was equalized considering intensity and stimulus time (intensity x duration). In continuous LI-AE-BFR, participants walked 20 minutes on the treadmill at 40% V_{peak} with bilateral cuffs (standard aneroid blood pressure cuff; 18-cm wide) inflated to a pressure of 50% of the AOP in the proximal region of the thighs. The intensity and pressure adopted in the present study was based on previous studies that analyzed continuous LI-AE-BFR on a treadmill (Souza-Pfeiffer et al., 2019; Silva et al., 2019). The cuff remained inflated throughout the exercise. The HIIE session consisted of ten 60-second runs at 80% of V_{peak}. The stimuli were interspersed with 60-seconds of passive recovery, totaling 20 min. A 60-second warm-up at 60% V_{peak} was performed 60 seconds before the HIIE session.

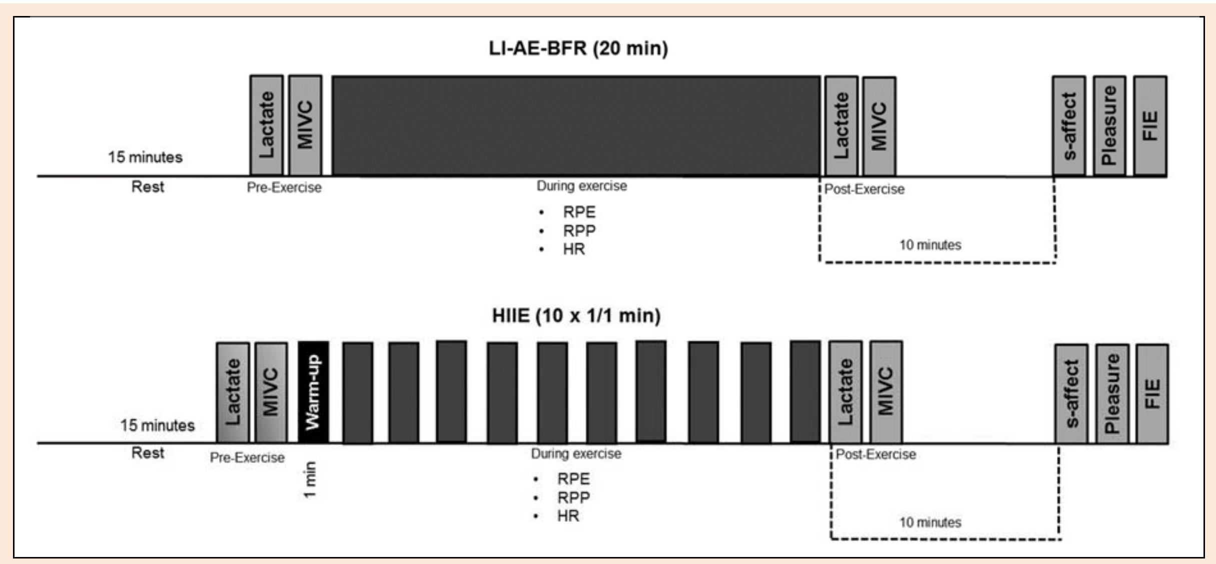

Figure 1. Overview of experimental sessions. FIE, future intention to exercise, HR, heart rate; MIVC, maximum voluntary isometric contraction; RPE, rating of perceived exertion; rating of perceived pain.

Measures

Perceptual responses

On the first visit, the first author of this study presented the scales used in this study to each participant and verbally explained the meaning of all verbal anchors, numbers, and the sensations that each represented. At the end of the explanation, the participant was asked about any doubts related to the scales presented.

Rating of perceived exertion (RPE)

RPE was recorded every two minutes in the LI-AE-BFR session. For the HIIE session, measurement was carried out in the final 10 seconds of each stimulus. The Borg scale (6-20) was used to assess RPE in both conditions. The scale was administered in accordance with recommendations described by Pageaux (2016). Therefore, written instructions, including the definition of effort, were provided before each experimental condition. The following definition of effort was used in our study: *"the conscious sensation of how difficult, heavy, and strenuous a physical task is."* To provide a reference regarding the evaluation of effort in the experimental conditions, participants were asked to anchor their RPE values relative to the effort experienced at exhaustion of the incremental test. Participants were instructed not to include other sensations, such as pain/discomfort, in their exertion rating. Considering the exercises characteristics tested in the present study, the exertion assessment was based on the following question: *"How hard is it for you to drive your legs and how heavy is your breathing?"*.

Rating of perceived pain (RPP)

RPP was determined using an 11-point Borg scale (0 - 10) and recorded at the same time points as RPE. The scale scores RPP on a 0 - 10: 0, no pain; 10, maximum pain. The participant was asked to report the degree of pain experienced in the anterior region of the thighs. As with RPE, written instructions, including the definition of pain, were provided before each experimental condition. To provide a reference for pain assessment, anchoring was performed based on the participant's memory, adopting procedures similar to Loenneke et al. (2016). A score of 10 (maximum pain) was anchored by the worst pain previously experienced. The participant was allowed to assign a score greater than 10 (11 or 12) if the pain experienced during the exercise exceeded the previous anchor. If the pain experienced during the exercise was much stronger than the previous perceptual experience, for example, 1.5 x more, the participant was asked to report a score of 15 points. RPP assessment was based on the following question: *"Based on this scale, what is the level of pain reported in the anterior region of your thigh?"*.

Affective response

The affective response was assessed 10 minutes after the experimental sessions using the feeling scale (FS; -5/+5) (Hardy and Rejeski, 1989). The FS is an 11-point bipolar scale ranging from -5 (very bad) to +5 (very good), which is translated and adapted into the language of the country where this study was carried out (Alves et al., 2019). The following instructions were read to the participant before each recording: *"While participating in the exercise, it is common to experience changes in mood. Some people find exercise pleasurable, while others find it unpleasant. Additionally, sentiment may vary over time. In other words, you can feel good and bad several times during exercise."* The participant was instructed to answer the following question: *"How did you feel during the exercise session?"***.**

Future intention to exercise

Intention to engage in a similar exercise in the future (FIE) was assessed using an 11-point probability scale (Juster Scale), ranging from 0 (no chance) to 10 (certain, almost certain) (Juster, 1966) 10 minutes after the end of the experimental sessions. The Juster Scale is mainly used in marketing areas, aiming to predict purchase intention. However, some evidence supports the use of this scale to predict possibilities associated with healthcare (Whitty et al., 2012). The Juster Scale was developed through an extensive experimental program at the US Department of the Census designed to develop both predictive and construct validity (Juster, 1966). In our study, the scale was independently translated by two authors of this study into the local language. Subsequently, the translated versions were compared and any discrepancies were discussed to a consensus was established. The participant was asked to answer the following question: *"How interested are you in participating in an exercise program similar to the one you just completed in the next two weeks?"***.**

Single-item measure of enjoyment during exercise

A single-item scale was used to assess enjoyment during the training sessions analyzed in the present study. The scale used had a 7-point score, ranging from 1 (not at all) to 7 (extremely) to answer one item: *"use the following scale to indicate how much you enjoyed this exercise session"* (Stanley and Cumming, 2010). The translation of the scale was carried out before the study, adopting the same procedure described in the previous topic. The scale was applied 10 minutes after the end of the experimental session.

Physiological responses

Heart rate

Heart rate (HR) was monitored continuously using a HR monitor (Polar H10; Polar Electro). For LI-AE-BFR, HR was recorded every two minutes, while in HIIE, HR was recorded at the end of each high-intensity stimulus. To determine the intensity of the session, the average of the ten measurements taken was calculated and, subsequently, the percentage in relation to peak HR (%HR_{peak}) was determined.

Blood lactate

Capillary blood lactate concentrations were measured at resting conditions and immediately after finishing each condition with a portable lactate analyzer (Detect TD-4261, Eco diagnostics) that was previously calibrated following the manufacturer's recommendations using a finger blood sample. In the LI-AE-BFR, measurements were performed with the cuff deflated.

Maximum isometric voluntary contraction

Pre-intervention and post-intervention strength (single measure) assessments were used to identify the presence of fatigue. Post-exercise measurement was performed immediately after collecting the capillary blood sample. A maximal isometric voluntary contraction (MIVC; kgf) (knee extension at 90º) of dominant member was performed on an isometric chair (Cefise®) with an attached load cell (Miotec™, Biomedical Equipments, Porto Alegre, RS, Brazil; maximum tension–compression = 100 kgf, the precision of 0.1 kgf, the maximum error of measurement = 0.33%). The load cell was calibrated before the start of the study following the manufacturer's recommendations. The participant was familiarized with the isometric knee extension test on the first visit and received instructions before each assessment. MIVC corresponds to the highest value reported during isometric knee extension with duration of 10 seconds. During the assessments, the participant was verbally encouraged by the researchers to perform maximal effort in the attempt.

Statistical analysis

Data normality was verified using the Shapiro-Wilk test. Skewness and kurtosis were also tested (z-score considered: -1.96 to +1.96) (Miot, 2017). A normal distribution was observed for HR, RPE, MIVC, FIE, affective response and pleasure, but not for capillary lactate and RPP (See Material Supplement). Two-way ANOVA (conditions x time) was used to analyze the effect of interventions on RPE, MIVC and HR. Bonferroni post-hoc was used to identified point differences. Paired Student's t-test was used to compare the effect of HIIE versus continuous LI-AE-BFR on affect, pleasure, FIE and session $\%HR_{peak}$. Cohen's d was used as a measure of effect size for these comparisons. The following classification was used to interpret Cohen's d: trivial effect (<0.19), small effect (0.20), medium effect (0.50), large effect (>0.80) (Cohen, 1992). Session mean RPP and absolute change in serum lactate concentrations were analyzed using nonparametric statistics (Wilcoxon test). The *r* coefficient was used as an effect size measure for these comparisons. The following classification was used to interpret the magnitude of the *r* coefficient: small effect (*r* = 0.10), medium effect (*r* = 0.30) and large effect (*r* = 0.50) (Pallant, 2020). Data that assumed normal distribution were reported as mean and standard deviation (SD), while non-parametric data are reported as means and 25th and 75th percentiles. A value of $p<0.05$ was adopted as significant. All analyses were performed using IBM SPSS Statistics software, version 24.0.

Results

Affect, future intention to exercise and pleasure

HIIE elicited a significantly higher session affective response than continuous LI-AE-BFR (t = 2.851; CI95% = 0.45, 3.94; p = 0.019; d = 0.9). Additionally, the intention to perform future exercise was greater in HIIE (t = 3.069; CI95% = 0.78, 5.21; p = 0.013; d = 0.97). In contrast, pleasure did not differ between the conditions tested (t = 1.481; CI95% = -0.36, 1.76; p = 0.173; d = 0.46). Individual responses to these variables are reported in Figure 2. Detailed descriptive statistics are reported in Supplementary Table 1 and Table 2.

Rating of perceived exertion and rating of perceived pain

For RPE, an effect of time (F (1.573,14.158) = 37.502; p < 0.001), but not condition (F (1,9) = 2.075; p = 0.184) or interaction effect (F (1.844, 16.594) = 1.481; p = 0.255) was observed. In HIIE, RPE was significantly lower in stimulus 1 compared to the other stimuli (p < 0.05). The RPE reported in stimulus 2 was similar to the RPE reported in stimulus 3, but significantly lower when compared to the RPE reported in the other stimuli (p < 0.05). RPE reported in stimuli 3, 4 and 5 were not significantly different, however, the RPE reported in stimuli 3 and 4 were significantly lower in relation to the RPE reported in stimuli 6, 7, 8, 9 and 10, while the RPE reported in stimulus 5 was lower than the RPE reported in stimulus 8. The RPE reported in stimuli 6, 7, 8, 9 and 10 were not statistically different.
In continuous LI-AE-BFR, the RPE reported after 8 minutes was significantly higher than the RPE reported after 2, 4, and 6 minutes of LI-AE-BFR. Additionally, the RPE reported at 6 minutes of continuous LI-AE-BFR was significantly lower than the RPE reported at 8, 10, 14, and 20 minutes of exercise. Changes in RPE in HIIE and continuous LI-AE-BFR are reported in Figure 3. The average RPP reported across the session was significantly higher

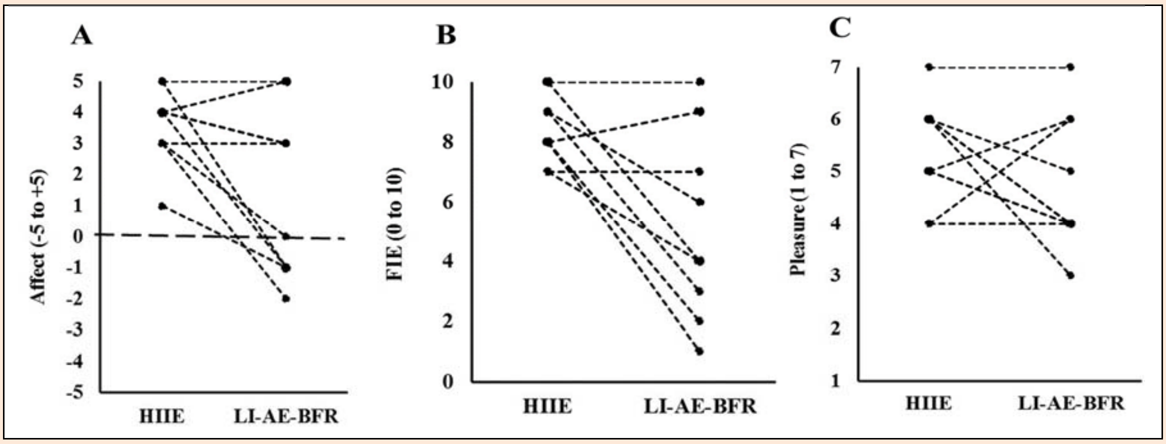

Figure 2. Psychological responses reported in HIIE and LI-AE-BFR. (A) Session affect. (B) Future intention to exercise. (C) Pleasure.

in continuous LI-AE-BFR than HIIE (2.42 [0.75-3.22] and 0.57 [0.0-1.1], respectively; z = -2.100; p = 0.036; *r* = 0.46).

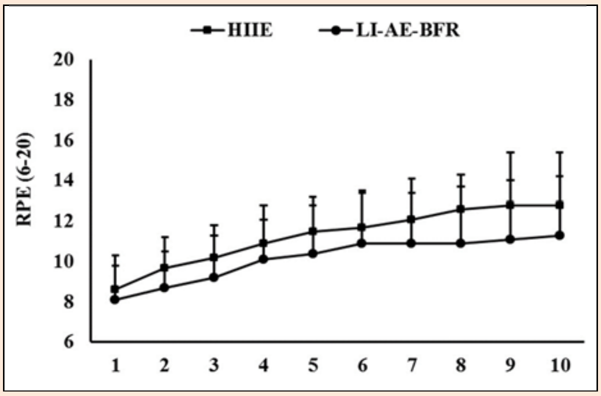

Figure 3. Rating of perceived exertion reported in HIIE and LI-AE-BFR.

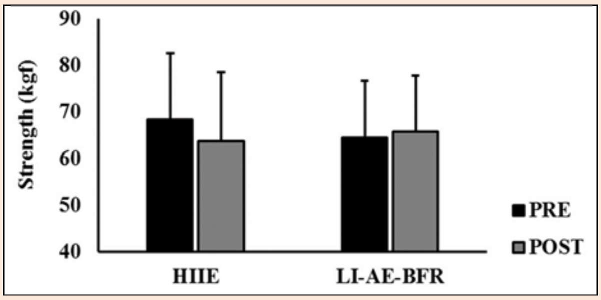

Figure 4. Maximum isometric voluntary contraction (MIVC) pre- and post-interventions.

Maximum isometric voluntary contraction (Fatigue measure)

For MIVC performance, we observed no effect of time (F (1,9) = 1.251; p = 0.292), condition (F (1,9) = 0.102; p = 0.757) or interaction (F (1,9) = 2.516; p = 0.147). There was no significant difference between the conditions (HIIE versus continuous LI-AE-BFR) at baseline (p = 0.237) or immediately after performing the exercise (p = 0.564). Likewise, no significant differences were reported between measurements taken before or after HIIE (p = 0.086) and continuous LI-AE-BFR (p = 0.597). MIVC performance is shown in Figure 4.

Heart rate

For HR, we observed an effect of time (F (1.773,15.957) = 12.683; p = 0.001), condition (F(1,9) = 287.869; p < 0.001) and interaction (F (3.458,31.118) = 5.386; p = 0.003). HIIE elicited significantly (p < 0.001) higher HR values than continuous LI-AE-BFR at all time points evaluated, with mean differences ranging from 33.9 to 45.2 bpm (d = 3.1 to 5.2). In HIIE, HR values recorded after the third stimulus were significantly (p < 0.05) higher than the values reported in the first stimulus. No significant differences were identified in continuous LI-AE-BFR between time-points. Changes in HR between HIIE and continuous LI-AE-BFR are reported in Figure 5. The average intensity of the session (%HR peak) was significantly higher in HIIE than in continuous LI-AE-BFR (80 ± 3.5% versus 58 ± 4.1%; p < 0.001; d = 4.2).

Blood lactate

Due to technical problems with the portable lactate analyzer, it was not possible to evaluate one of our participants. The absolute difference in capillary lactate concentrations (post-exercise values – pre-exercise values) was significantly higher in HIIE than continuous LI-AE-BFR (3.6 mmol/L [3.14-4.85] vs 1 mmol/L [1-3.45]; z = -2.194; p = 0.028; *r* = 0.51). Individual responses to absolute change in capillary lactate concentration are reported in Figure 6.

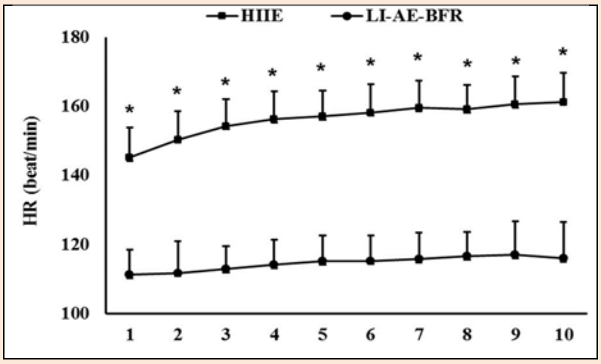

Figure 5. Heart rate reported in HIIE and LI-AE-BFR.

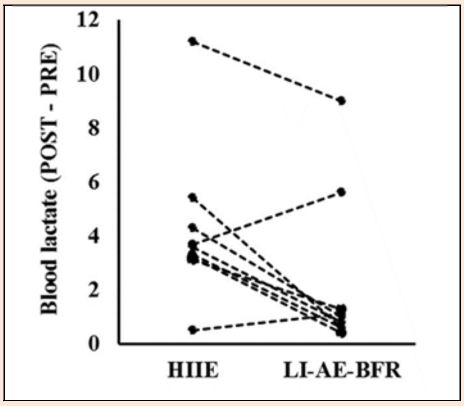

Figure 6. Absolute change in lactate concentrations in HIIE and LI-AE-BFR.

Discussion

The purpose of this study was to analyze the effect of HIIE versus continuous LI-AE-BFR on psychophysiological responses, including pleasure, affect, FIE, HR and blood lactate. To our knowledge, this is the first study that investigated these responses between HIIE and continuous LI-AE-BFR matched by their workload. As our main result, we identified that HIIE elicited better affective responses as well as FIE than continuous LI-AE-BFR. Conversely, continuous LI-AE-BFR resulted in higher RPP despite similar RPE between conditions. Regarding physiological responses, HR and absolute changes in lactate concentrations were significantly higher in HIIE. On the other hand, there was no statistically significant reduction in post-exercise MIVC in either exercise condition, indicating the aerobic exercise protocols did not elicit muscular fatigue.

These results suggest that HIIE elicits more pronounced acute physiological stress than continuous LI-AE-BFR, while promoting a greater positive affective response and intention for future engagement.

Perceptual responses

The acute affective response during exercise is a clinically relevant variable given the affective responses reported during exercise predicts future participation and long-term engagement in physical exercise (Williams et al., 2008). Exercise intensity usually shows an inverse relationship with the affective response reported in aerobic exercise, with intensities above ventilatory thresholds eliciting reduced affective responses (Jung et al., 2014; Parfitt and Hughes, 2009). The results presented in the current study do not support this inverse dose-response relationship between exercise intensity and affect as HIIE elicited higher positive affective responses than continuous LI-AE-BFR. Furthermore, future intention to engage in exercise was lower in continuous LI-AE-BFR. Some factors related to the configuration of the exercise models tested in our study may explain, in part, these results. For example, the application of BFR can substantially heighten muscle pain ratings reported during LI-AE (Kilgas et al., 2022). In our study, RPP was significantly higher in continuous LI-AE-BFR than in HIIE despite the reduced absolute intensity of exercise. In this case, we speculate that the pain experienced in continuous LI-AE-BFR may have contributed to the lower affective response and future practice intention and why HIIE was perceived with higher affective responses despite prior research. In this case, although the external load is low in LI-AE-BFR, this type of exercise can increase interoceptive cues, especially pain/discomfort, generating lower affective responses (Dual Mode Theory).

Furthermore, the LI-AE-BFR protocol consisted of 20-minutes of continuous walking, while the HIIE consisted of 10 1-minute stimuli interspersed with 1-minute of passive recovery. The intermittent nature of this protocol has been identified as one of the factors potentially responsible for the higher future intention to exercise in this type of exercise compared to lower intensity continuous exercise (Jung et al., 2014). In an intermittent protocol such as the one as adopted in our study, the participant can have multiple successful experiences that may reflect an increase in self-efficacy, increasing the chances of involvement, given that individuals are attracted to engage in behaviors that they feel confident in to perform (Jung et al., 2014). In addition, we speculate that the HIIE protocol may have minimized monotony, as well as producing a "rebound" affectual response that culminated in more pleasure during the recovery intervals. In other words, the participant would experience a sensation of "relief" when the stimulus ceased (responsible for eliciting substantial interoceptive signals), resulting in a more positive affective response in the recovery intervals.

Regarding RPE, no significant difference between exercises was reported at any of the time points evaluated in our study. While the findings of this study differ with those from other studies involving comparisons between high-intensity exercise versus LI-AE-BFR (Corvino et al., 2017; Thomas et al., 2018; Kim et al., 2016), they concur with others (Kilgas et al., 2022; Lauver et al., 2021). Variations in HIIE and LI-AE-BFR protocols used by previous studies may explain the divergence between ours and their findings. For instance, Corvino et al. (2017) reported higher RPE during a high-intensity exercise protocol using 5 x 2 min at ≥90% of peak power in comparison with a LI-AE-BFR protocol that used 5 x 2 min at 30% of peak power. In our study, we used 80% of V_{peak} and 40% of V_{peak} in HIIE and LI-AE-BFR, respectively, adopting a similar volume of work (intensity x duration), which might help to explain the absence in difference in RPE between sessions. Using a similar design, Silva et al. (2019) identified similar RPE between HIIE (6 stimuli of 90 seconds at 80% VO_{2peak}, with 90 seconds of active rest at 40% VO_{2peak}) versus continuous LI-AE-BFR (18 minutes at 40% of VO_{2peak} with a cuff inflated at 50% AOP), both performed on a treadmill. From these results, it is possible to infer that a longer period of exercise, together with the BFR stimulus, may have compensated for a lower intensity in LI-AE-BFR, generating a RPE similar to that observed in HIIE. Future studies should use matched-workload paradigms as this may help the comparison between exercise and studies.

Two theories have been proposed to justify the increase in RPE during exercise: (i) afferent feedback model and (ii) corollary discharge model. The afferent feedback model supports that increased effort results from the brain processing of signals provided by afferent feedback from skeletal muscle, heart and/or lungs (Morre and Marcora, 2015). On the other hand, the corollary discharge model supports that the increase in effort has a central origin, with the magnitude of the RPE being dependent on the magnitude of the central command (Morre and Marcora, 2015). In this case, high-intensity exercise or exercises performed under a substantial level of fatigue can elicit an increase in RPE. In our study, although RPE was similar between conditions, HR and blood lactate were significantly higher in HIIE. In this case, the afferent feedback model may not explain our results. None of the exercises generated significant declines in MIVC (fatigue measure). In part, this aspect could justify the moderate RPE reported during the conditions. Furthermore, we do not rule out the possibility that cognitive factors may have influenced the RPE reported in both conditions.

Physiological responses

It has previously been shown that LI-AE-BFR can elicit a more pronounced increase in blood lactate than LI-AE without BFR (work-matched) (Thomas et al., 2018; Kilgas et al., 2022). Furthermore, Kilgas et al. (2022) identified similar post-exercise blood lactate concentrations between LI-AE-BFR and high-intensity exercise. In contrast, we identified significantly greater increases in lactate concentrations in HIIE than in continuous LI-AE-BFR. Some methodological aspects may justify this divergence, including type of exercise and BFR pressure. Kilgas et al. (2022) used cycling and 80% of the AOP, while in our study treadmill exercise was used with 50% of the AOP. Furthermore, the disparity between studies can be justified by the reported difference in work rates in relation to metabolic transition thresholds (Tschakert et al., 2022).

Loenneke et al. (2012) identified that LI-AE-BFR performed on a treadmill does not cause a significant increase in blood lactate concentrations. In our study, most (7/9) of the participants analyzed exhibited an increase in capillary lactate concentrations of less than 2 mmol/L in continuous LI-AE-BFR. Conversely, eight volunteers showed more pronounced increases in capillary lactate concentrations in the HIIE condition (> 2 mmol/L). It is worth noting that in the two exercise models tested in the current study, there was a certain level of variability in changes in capillary lactate. This aspect can be justified by the parameter adopted to personalize the exercise intensity (%V_{peak}). Possibly, there was some variability in %V_{peak} relative to metabolic transition thresholds (Tschakert et al., 2022).

The reduced production of metabolites in continuous LI-AE-BFR compared to HIIE justifies, in part, the more pronounced cardiovascular response in HIIE, considering the role of the metaboreflex in controlling cardiovascular responses. Increasing HR during aerobic exercise appears to be important for improving aerobic capacity (Moholdt et al., 2014); increased HR heightens mechanical stress on the heart and, chronically, can generate an increase in stroke volume and VO_{2max} (Smith et al., 2021). Therefore, it would be expected that cardiorespiratory adaptations are more pronounced in HIIE programs than in LI-AE-BFR. In support, Oliveira et al. (2016) identified higher effect size estimates in HIIE versus LI-AE-BFR (0.9 versus 0.3, respectively) for changes in VO_{2max} following 4 weeks of training, although between-group differences did not reach statistical significance.

Regarding fatigue, we did not identify significant declines in strength after continuous LI-AE-BFR. These findings are in line with previously published results (Ogawa et al., 2012; Yamada et al., 2021). However, these results should not be generalized to all aerobic exercise models performed with BFR. For example, Kilgas et al. (2022) identified significant and more pronounced declines in MIVC after low-intensity cycling with BFR than low- and high-intensity cycling without BFR. It is worth mentioning that in our protocol the HIIE did not induce significant declines in post-exercise MIVC. We speculate that this result is explained by the duration of the exercise with a possible dose-dependent relationship between the duration of the activity and the decline in muscle strength (Millet and Lepers, 2004). When analyzing the results reported by Millet and Lepers (2004), it is possible to identify strength declines above 20% in continuous runs lasting 200 minutes, that is, a much longer duration than that used in our intervention.

Limitations

This study has limitations which should be considered before interpreting the results. Firstly, in relation to BFR exercise, the use of pressures above 50% AOP can worsen the perceptual experience, in addition to maximizing physiological stress in BFR exercise (Kilgas et al., 2022; Souza-Pfeiffer et al., 2019). For HIIE, it has already been demonstrated that the affective and physiological response can differ between different exercise models of this nature (Follador et al., 2018). However, we highlight that the choice for a low-volume HIIE model was made to equalize exercise time and work between conditions. Secondly, our affect assessments were performed only 10 minutes after exercise; although we requested that the response reflect the affect experienced during the exercise, our results may not accurately reflect the feeling experienced during the entire bout of exercise. This limitation also applies to the lactate and HR carried out in our study; the lactate measurements were taken before and immediately after exercise and therefore may not reflect the effect experienced at different times of exercise. Regarding HR, there was no monitoring during the HIIE recovery intervals. As previously explained, the parameter adopted to determine the intensity of the exercise models tested in the present study may have generated significant variability in work rates relative to metabolic transition thresholds. Furthermore, we must point out that the scale used to assess future exercise intention is not specific to exercise, this being the first study using it for these purposes. Regarding the scale used to assess pleasure, we should highlight that, although this instrument is widely used in studies on the topic and is an easy-to-understand scale, we could not identify any validation study for this scale.

We recommend that future studies analyze these exercise models, testing different BFR pressures with LI-AE and include affect measures taken during and after exercise as well as in longitudinal designs that could inform practice. Preferably, we recommend that future studies adopt treadmill exercise due to greater ecological validity. Furthermore, although our sample size calculation revealed sufficient sample power in our study, larger studies are important to confirm our findings.

Conclusion

Continuous low-intensity aerobic exercise with blood flow restriction elicits less physiological response, affective response, and future engagement intention than high-intensity interval exercise in untrained men. On the other hand, pain ratings were higher in continuous low-intensity aerobic exercise with blood flow restriction and RPE and fatigue did not differ between the conditions tested.

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Key points

- Continuous low-intensity aerobic exercise with blood flow restriction elicited reduced affective responses when compared to high-intensity interval exercise;
- Future engagement intention was greater in high-intensity interval exercise than in continuous low-intensity aerobic exercise with blood flow restriction;
- Continuous low-intensity aerobic exercise with blood flow restriction elicited less pronounced physiological stress than high-intensity interval exercise.

AUTHOR BIOGRAPHY

Victor S. de QUEIROS
Employment
Graduate Program in Health Sciences, Federal University of Rio Grande do Norte, Natal-RN, Brazil.
Degree
MSc (Physical Education).
Research interests
Blood flow restriction training, resistance training, muscle hypertrophy.
E-mail: victor.sabino.121@ufrn.edu.br

Nicholas ROLNICK
Employment
The Human Performance Mechanic, NYC, NY USA
Degree
Doctor of Physical Therapy, Master of Science in Health Promotion Management
Research interests
Blood flow restriction training, cuff design and features associated with blood flow restriction, muscle hypertrophy
E-mail: nick@thebfrpros.com

Angelo SABAG
Employment
Discipline of Exercise and Sport Science, Faculty of Medicine and Health, The University of Sydney, Sydney, Australia.
Degree
PhD.
Research interests
Physiological adaptations aerobic and resistance training in health and disease.
E-mail: angelo.sabag@sydney.edu.au

Phelipe WILDE
Employment
Graduate Program in Health Sciences, Federal University of Rio Grande do Norte, Natal-RN, Brazil.
Degree
MSc (Physical Education).
Research interests
High-intensity exercise, immune system, HIV.
E-mail:
phelipe.varela.108@ufrn.edu.br

Thiago PEÇANHA
Employment
Department of Sport and Exercise Sciences da Manchester Metropolitan University - United Kingdom.
Degree
PhD
Research interests
Cardiovascular physiology, therapeutic effects of physical exercise in chronic non-communicable diseases.
E-mail: pecanhatiago@gmail.com

Rodrigo Ramalho ANICETO
Employment
Federal Institute of Education, Science and Technology of Rio Grande do Norte, Currais Novos-RN, Brazil.
Degree
PhD
Research interests
Blood flow restriction training, resistance training, exercise psychophysiology.
E-mail: rodrigo-afa@hotmail.com

Roberto Felipe Câmara ROCHA
Employment
Department of Physical Education, Federal University of Rio Grande do Norte, Natal-RN, Brazil.
Degree
Undergraduate student (Physical Education).
Research interests
Physical performance, blood flow restriction training, cardiovascular responses.
E-mail: feliperoccha@gmail.com

Douglas Z. DELGADO
Employment
Graduate Program in Physical Education, Federal University of Rio Grande do Norte, Natal-RN, Brazil
Degree
B.Sc. (Physical Education)
Research interests
Post-activation potentiation, neuromuscular responses, basketball
E-mail: douglas-7000@hotmail.com

Breno Guilherme de Araújo Tinôco CABRAL
Employment
Department of Physical Education, Federal University of Rio Grande do Norte, Natal-RN, Brazil
Degree
PhD.
Research interests
Biological maturation, sports initiation, volleyball, resistance training, blood flow restriction training.
E-mail: brenotcabral@gmail.com

Paulo Moreira Silva DANTAS
Employment
Department of Physical Education, Federal University of Rio Grande do Norte, Natal-RN, Brazil
Degree
PhD.
Research interests
Resistance training, high-intensity exercise, blood flow restriction training, HIV, exercise physiology, adapted sport.
E-mail: pgdantas@icloud.com

✉ **Victor S. Queiros**
Graduate Program in Health Sciences, Federal University of Rio Grande do Norte (UFRN), Natal-RN, Brazil

Supplment Table 1. LI-AE-BR descriptive statistics.

Variable	Mean (SD)	Skewness (SE)	Kurtosis (SE)	p-value (shapiro-wilk test)
Feeling	1.4 (2.6)	0.160 (0.687)	-1.813 (1.334)	0.085
FIE	5.6 (3.3)	0.164 (0.687)	-1.488 (1.334)	0.382
Pleasure	4.7 (1.2)	0.705 (0.687)	-0.493 (1.334)	0.102
MIVC PRE	64.4 (12.2)	0.436 (0.687)	-0.784 (1.334)	0.666
MIVC POST	65.7 (12.0)	0.927 (0.687)	0.991 (1.334)	0.223
Heart rate 1	111.3 (7.2)	-1.141 (0.687)	2.123 (1.334)	0.428
Heart rate 2	111.9 (9.1)	0.181 (0.687)	1.700 (1.334)	0.759
Heart rate 3	113.0 (6.6)	-0.647 (0.687)	1.878 (1.334)	0.692
Heart rate 4	114.3 (7.1)	-0.457 (0.687)	-0.064 (1.334)	0.954
Heart rate 5	115.3 (7.5)	0.445 (0.687)	-0.354 (1.334)	0.689
Heart rate 6	115.4 (7.3)	-0.792 (0.687)	1.117 (1.334)	0.826
Heart rate 7	115.9 (7.7)	-0.299 (0.687)	-0.957 (1.334)	0.329
Heart rate 8	116.8 (7.08)	0.025 (0.687)	-0.752 (1.334)	0.726
Heart rate 9	117.1 (9.8)	0.507 (0.687)	-0.325 (1.334)	0.678
Heart rate 10	116.1 (10.6)	0.981 (0.687)	-0.533 (1.334)	0.048
RPE 1	8.1 (1.7)	0.253 (0.687)	-1.363 (1.334)	0.396
RPE 2	8.7 (1.8)	0.300 (0.687)	-0.390 (1.334)	0.803
RPE 3	9.2 (2.1)	0.071 (0.687)	-0.537 (1.334)	0.876
RPE 4	10.1 (2.07)	-0.351 (0.687)	-1.00 (1.334)	0.451
RPE 5	10.4 (2.4)	-0.114 (0.687)	-1.108 (1.334)	0.624
RPE 6	10.9 (2.5)	-0.409 (0.687)	-0.916 (1.334)	0.229
RPE 7	10.9 (2.5)	-0.409 (0.687)	-0.916 (1.334)	0.229
RPE 8	10.9 (2.8)	-0.626 (0.687)	-0.700 (1.334)	0.214
RPE 9	11.1 (2.9)	-0.590 (0.687)	-0.480 (1.334)	0.592
RPE 10	11.3 (2.9)	-0.791 (0.687)	-0.283 (1.334)	0.288
MEAN RPP	2.0 (1.6)	-0.283 (0.687)	-1.326 (1.334)	0.182
BL	1.0 (2.9)#	1.916 (0.717)	2.853 (1.400)	>0.001

= median (interquartile range; non-parametric); SD = standard deviation; SE = standard error.

Supplement Table 2. HIIE descriptive statistics.

Variable	Mean (SD)	Skewness (SE)	Kurtosis (SE)	p-value (shapiro-wilk test)
Feeling	3.6 (1.1)	-1.072 (0.687)	1.855 (1.334)	0.108
FIE	8.6 (1.1)	-0.041 (0.687)	-1.457 (1.334)	0.124
Pleasure	5.4 (0.96)	-0.111 (0.687)	-0.623 (1.334)	0.245
MIVC PRE	68.2 (14.4)	0.030 (0.687)	0.707 (1.334)	0.949
MIVC POST	63.6 (14.8)	0.147 (0.687)	1.943 (1.334)	0.625
Heart rate 1	145.2 (8.6)	1.086 (0.687)	0.740 (1.334)	0.174
Heart rate 2	150.4 (8.2)	0.381 (0.687)	-0.873 (1.334)	0.605
Heart rate 3	154.3 (7.7)	-0.352 (0.687)	-0.449 (1.334)	0.740
Heart rate 4	156.2 (8.1)	-0.006 (0.687)	-1.070 (1.334)	0.555
Heart rate 5	157.1 (7.3)	0.256 (0.687)	-0.670 (1.334)	0.223
Heart rate 6	158.2 (8.1)	0.243 (0.687)	-1.108 (1.334)	0.295
Heart rate 7	159.6 (7.8)	-0.317 (0.687)	-0.549 (1.334)	0.709
Heart rate 8	159.2 (7.0)	0.175 (0.687)	0.031 (1.334)	0.409
Heart rate 9	160.5 (8.2)	0.105 (0.687)	-0.502 (1.334)	0.859
Heart rate 10	161.3 (8.4)	-0.266 (0.687)	0.676 (1.334)	0.886
RPE 1	8.6 (1.7)	0.451 (0.687)	0.645 (1.334)	0.549
RPE 2	9.7 (1.5)	0.836 (0.687)	0.973 (1.334)	0.126
RPE 3	10.2 (1.6)	0.132 (0.687)	-0.989 (1.334)	0.525
RPE 4	10.9 (1.9)	0.057 (0.687)	-0.874 (1.334)	0.883
RPE 5	11.5 (1.7)	0.330 (0.687)	-1.001 (1.334)	0.398
RPE 6	11.75 (1.8)	0.083 (0.687)	-1.243 (1.334)	0.694
RPE 7	12.1 (2.02)	-0.771 (0.687)	0.714 (1.334)	0.679
RPE 8	12.6 (1.7)	0.119 (0.687)	-1.059 (1.334)	0.591
RPE 9	12.8 (2.6)	-0.194 (0.687)	0.372 (1.334)	0.782
RPE 10	12.8 (2.6)	-0.194 (0.687)	0.372 (1.334)	0.782
MEAN RPP	0.57 (1.1)#	1.379 (0.687)	1.735 (1.334)	0.043
BL	3.6 (1.7)#	1.822 (0.717)	4.881 (1.400)	0.014

= median (interquartile range; non-parametric); SD = standard deviation; SE = standard error