

Research article

## Physiological and Psychological Responses during Low-Volume High-Intensity Interval Training Sessions with Different Work-Recovery Durations

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### Abstract

We compared physiological and psychological responses between low-volume high-intensity interval training (LV-HIIT) sessions with different work-recovery durations. Ten adult males performed two LV-HIIT sessions in a randomized, counter-balanced order. Specifically, 60/60 s LV-HIIT and 30/30 s LV-HIIT. Oxygen uptake ( $\text{VO}_2$ ), carbon dioxide output ( $\text{VCO}_2$ ), ventilation (VE), respiratory exchange ratio (RER), perceived exertion (RPE), and affect were assessed. During intervals, the  $\text{VO}_2$  ( $3.25 \pm 0.57$  vs.  $2.83 \pm 0.50$  L/min),  $\text{VCO}_2$  ( $3.15 \pm 0.61$  vs.  $2.93 \pm 0.58$  L/min), VE ( $108.59 \pm 27.39$  vs.  $94.28 \pm 24.98$  L/min), and RPE ( $15.9 \pm 1.5$  vs.  $13.9 \pm 1.5$ ) were higher ( $p \leq 0.01$ ), while RER ( $0.98 \pm 0.05$  vs.  $1.03 \pm 0.03$ ) and affect ( $-0.8 \pm 1.4$  vs.  $1.1 \pm 2.0$ ) were lower ( $p \leq 0.007$ ) in the 60/60 s LV-HIIT. During recovery periods,  $\text{VO}_2$  ( $1.85 \pm 0.27$  vs.  $2.38 \pm 0.46$  L/min),  $\text{VCO}_2$  ( $2.15 \pm 0.35$  vs.  $2.44 \pm 0.45$  L/min), and affect ( $0.6 \pm 1.7$  vs.  $1.7 \pm 1.8$ ) were lower ( $p \leq 0.02$ ), while RER ( $1.20 \pm 0.05$  vs.  $1.03 \pm 0.05$ ;  $p < 0.001$ ) was higher in the 60/60 s LV-HIIT. Shorter LV-HIIT (30 s) elicits lower physiological response and attenuated negative affect than longer LV-HIIT (60 s).

**Key words:** Exercise, interval training, affective response, pleasure, physiological response.

### Introduction

Low-volume high-intensity interval training (LV-HIIT) is considered a practical and tolerable protocol for healthy and clinical populations (Gibala et al., 2012). LV-HIIT is performed at a 'vigorous' to 'near maximal' efforts (Weston et al., 2014), usually between 85-95% of maximal heart rate ( $\text{HR}_{\text{max}}$ ) (Gibala et al., 2012). LV-HIIT protocols involve a low amount of work at 'vigorous' to 'near maximal' efforts, which usually lasted 10 minutes or less. For example, 10 x 60 s intervals at 90% of  $\text{HR}_{\text{max}}$  interspersed by 60 s of recovery (Gibala et al., 2014). From a physiological perspective, LV-HIIT has demonstrated efficacy to improve cardiorespiratory fitness (Currie et al., 2013; Gillen et al., 2013) and cardiometabolic risk factors in several populations (Ciolac et al., 2009; Hood et al., 2011; Little et al., 2010; 2011).

However, the psychological responses to interval training have been the focus of an intense and polarized debate (Biddle and Batterham, 2015; Hardcastle et al., 2014; Stork et al., 2017). Affective response (i.e. feeling of pleasure/displeasure) during interval training has been

debated because it is considered an important factor related to exercise adherence (Garber et al., 2011). Previously, some studies have shown a negative affect during LV-HIIT (Frazao et al., 2016; Olney et al., 2018; Thum et al., 2017), while other studies have reported a positive affect (Jung et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015). It seems that this disagreement about the affective response to LV-HIIT may be related to the different designs of the protocols used, mainly regarding the different intensities and durations of the intervals and recovery periods (Stork et al., 2017). LV-HIIT protocols involving interval duration  $\leq 60$  s and performed at an intensity  $\leq 85\%$  of  $\text{HR}_{\text{max}}$  elicit a positive affective response (i.e. feeling of pleasure) (Martinez et al., 2015). On the other hand, LV-HIIT protocols involving interval duration  $\geq 60$  s performed at an intensity greater than to 85% of  $\text{HR}_{\text{max}}$  elicit a negative affective response (Frazao et al. 2016; Olney et al. 2018; Thum et al. 2017). However, it remains unclear whether only the work-recovery duration modulates the affective response when the LV-HIIT protocols are matched by the work-recovery ratio and the total work performed.

It should be noted that the physiological responses during interval training may be modulated by the work-recovery duration (Buchheit and Laursen, 2013). Overall, shorter intervals elicit lower oxygen uptake, HR, and blood lactate concentration when the total work performed is matched (Tschakert et al., 2015; Tucker et al., 2015). Different combinations of work-recovery durations and intensity may generate a balance or imbalance between lactate production and clearance (Tschakert and Hofmann, 2013; Tschakert et al., 2015). We have observed previously that the affective response during HIIT is more negative when the HR and perceived exertion are higher, which occurs especially in the end of the exercise session. We argue that it occurs when a metabolic imbalance is present (i.e. higher lactate production than clearance) (Frazao et al., 2016; Oliveira et al., 2013). More recently, we have demonstrated that the affective response to 60/60 s LV-HIIT is negatively correlated with time spent above respiratory compensation point (Farias-Junior et al. 2018). Taken together, it seems that work-recovery combinations that elicit a state of metabolic imbalance are associated with negative affective response to HIIT. The present study has investigated whether a LV-HIIT session performed with shorter work-recovery duration (i.e. 30 s) elicits lower physiological response and, as a result, lower perceived exertion and affective response

less negative than a LV-HIIT protocol performed with longer work-recovery duration (i.e. 60 s).

## Methods

### Participants

A total of 18 participants were approached for the study and 10 men completed the study (age:  $26.6 \pm 4.8$  years; BMI:  $25.6 \pm 2.3$  kg/m<sup>2</sup>;  $VO_{2peak}$ :  $49.3 \pm 5.3$  mL/kg/min;  $V_{max}$ :  $16.4 \pm 1.9$  km/h;  $HR_{max}$ :  $193.3 \pm 7.5$  bpm) (see Figure 1). The participants were recruited from the invitation disclosed in university settings, e-mail and online social networks. Individuals who agreed to participate in the study completed an in-lab interview for eligibility confirmation. The study was conducted from June 2016 to October 2016. Inclusion criteria were: i) men aged from 18 to 35 years; ii) apparently healthy according to the Physical Activity Readiness Questionnaire; and iii) having experience in treadmill running. Exclusion criteria were: i) BMI < 18.5 kg/m<sup>2</sup> or > 30.0 kg/m<sup>2</sup>; and (ii) injury during the study period; iii) use of medication that affects cardiorespiratory function. The participants were informed about all procedures related to the study, and gave written informed consent. The study was approved by the Ethics Committee of University (protocol 706.789/2014).

### Experimental design

We conducted a randomized, counter-balanced order trial including two interventions. The trial compared oxygen uptake, carbon dioxide output, respiratory exchange ratio, HR, rating of perceived exertion, and affect between two

LV-HIIT protocols with different work-recovery durations (i.e. 60/60 s vs. 30/30 s), but matched by work-recovery ratio and total work performed (i.e. 1:1 and 10 minutes, respectively). The study was reported in accordance with the CONSORT Statement guidelines (Boutron et al., 2017). Each participant performed the following procedures: i) initial screening; ii) maximal graded exercise test; and iii) a single session of 60/60 s LV-HIIT and 30/30 s LV-HIIT. Initially, the participants were screened using the Physical Activity Readiness Questionnaire. Afterward, they underwent a clinical examination where body weight (kg) and height (m) were measured. Body mass index (BMI) was calculated as weight (kg) divided by the square height in meters (kg/m<sup>2</sup>). After 48 h of the initial screening, participants performed a maximal graded exercise test on a treadmill. At the end of the maximal graded test, the two experimental sessions (60/60 s LV-HIIT and 30/30 s LV-HIIT) were scheduled with one-week interval between each one. A computer-based randomization (<http://www.randomization.com>) was used to determine the order of the exercise sessions. Only the participants were blinded to the order of interventions. Figure 1 shows the flowchart of the study. All procedures were performed in the afternoon (between 1:00-4:00 p.m.). Participants were asked to avoid moderate-vigorous physical activity, caffeinated products, and alcohol consumption as well as to maintain a good sleeping pattern and normal dietary habits 24 h before the graded exercise test to volitional exhaustion and experimental sessions.

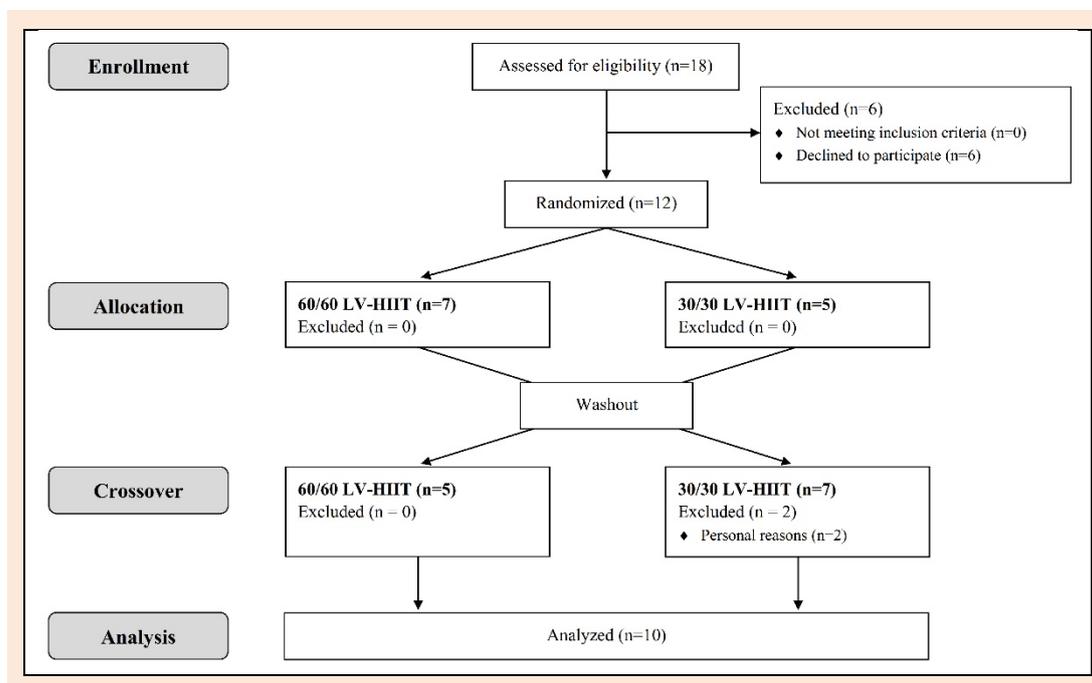


Figure 1. Flowchart of the study.

### Graded exercise test to volitional exhaustion

Participants performed a graded exercise test to volitional exhaustion on a motorized treadmill (RT350, Movement<sup>®</sup>, São Paulo, Brazil) to determine the maximal velocity ( $V_{max}$ ),  $HR_{max}$  and peak oxygen uptake ( $VO_{2peak}$ ). The test started at 4 km/h for 1 minute, followed by fixed increments of 1 km/h per minute until volitional exhaustion. HR

was continuously recorded throughout the test using a HR monitor (RS800cx, Polar Electro<sup>®</sup>, Oy, Kempele, Finland). Oxygen uptake was continuously recorded using a breath-by-breath gas exchange automatic system (Metalyzer<sup>®</sup> 3B, Cortex Biophysik GmbH, Leipzig, Germany).  $V_{max}$  was defined as the velocity reached during the last full stage added with the proportional time in the following incommen-

plete stage before the volitional exhaustion (Midgley et al., 2009). For example, if the participant completed the 13 km/h stage and reached the volitional exhaustion in the next 30 s during the 14 km/h stage the  $V_{\max}$  was defined as 13.5 km/h.  $VO_{2\text{peak}}$  was considered as the higher value of the last 30 s of oxygen uptake before volitional exhaustion (Midgley et al., 2009).

### 30/30 s and 60/60 s LV-HIIT sessions

Participants performed both LV-HIIT sessions on a motorized treadmill (RT350, Movement<sup>®</sup>, São Paulo, Brazil). The 60/60 s LV-HIIT protocol consisted of 10 x 60 s intervals at 100% of  $V_{\max}$  interspersed with 60 s of passive recovery. The 30/30 s LV-HIIT protocol consisted of 20 x 30 s intervals at 100% of  $V_{\max}$  interspersed with 30 s of passive recovery. Both LV-HIIT sessions lasted 30 minutes, including 5 minutes of warm-up and 5 minutes of cool-down at 4 km/h. Both exercise sessions were performed at the same mean load ( $V_{\text{mean}}$ ,  $8.2 \pm 0.9$  km/h) according to equation  $V_{\text{mean}} = (V_{\text{peak}} \times t_{\text{peak}} + V_{\text{rec}} \times t_{\text{rec}}) / (t_{\text{peak}} + t_{\text{rec}})$  (Tschakert and Hofmann, 2013). The HR (bpm) was recorded every 1 minute during LV-HIIT sessions. The  $VO_2$  was continuously recorded (breath-by-breath) using a gas exchange automatic system (Metalyzer 3B, Cortex Biophysik GmbH<sup>®</sup>, Leipzig, Germany). Energy expenditure in the sessions were calculated including warm-up and cool-down periods.

### Physiological measurements

During LV-HIIT sessions, oxygen uptake ( $VO_2$ ), carbon dioxide output ( $VCO_2$ ), and ventilation (VE) were continuously recorded (Metalyzer<sup>®</sup> 3B, Cortex Biophysik GmbH, Leipzig, Germany) and the mean values of every 30 s were considered for analysis. HR (bpm) was continuously recorded throughout the LV-HIIT sessions using a HR monitor (RS800cx, Polar Electro<sup>®</sup>, Oy, Kempele, Finland) and the HR of the last 5 s of interval and recovery periods were considered for analysis. For comparison between the two LV-HIIT protocols the equivalent times for interval and recovery periods (i.e. 20%, 40%, 60%, 80%, and 100%) were considered; i.e. the 2<sup>nd</sup>, 4<sup>th</sup>, 6<sup>th</sup>, 8<sup>th</sup>, and 10<sup>th</sup> interval and recovery periods for the 60/60 s LV-HIIT protocol and the 4<sup>th</sup>, 8<sup>th</sup>, 12<sup>th</sup>, 16<sup>th</sup>, and 20<sup>th</sup> interval and recovery periods for the 30/30 s LV-HIIT protocol.

### Rating of Perceived Exertion

Whole-body perceived exertion was assessed using the Borg RPE Scale (RPE, 6-20) (Borg, 1998). We explained the meaning of perceived exertion to the participants at the initial screening and before starting each LV-HIIT session. Perceived exertion was defined as the subjective intensity of effort, strain, and/or fatigue felt during exercise (Robertson and Noble, 1997). The low and high perceptual anchors for the Borg RPE Scale were established during the graded exercise test. A rating of 6 (low anchor, “very, very light”) was assigned to the lowest exercise intensity, while a rating of 20 (high anchor, “very, very hard”) was assigned to the highest exercise intensity. The participants were asked to rate “what is your perceived exertion in this

moment of the exercise session?” RPE values were recorded in the last 10 s of each interval and recovery period.

### Affective response

Affective response (i.e. feeling of pleasure/displeasure) was assessed using the Feeling Scale (FS, -5/+5) (Hardy and Rejeski, 1989). FS is an 11-point, single-item bipolar scale with a dimensional model ranging from +5 to -5 that is commonly used to measure affective valence (i.e. pleasure/displeasure) during exercise (Ekkekakis et al., 2011). We explained the meaning of affective response to the participants at the initial screening and before starting each LV-HIIT session. Affect was defined as the subjective feeling of ‘goodness’ or ‘badness’ felt during exercise which occurs regardless of emotions (Ekkekakis, 2003). The participants were asked to rate “how do you feel at this moment of the exercise session?” The affective responses were recorded in the last 10 s of each interval and recovery period. The RPE and Feeling Scale were presented in a randomized order to the participants.

### Statistical analysis

Data presented a normal distribution according to Shapiro-Wilk test. Skewness and kurtosis were also tested (z-score considered: -1.96 to +1.96). A paired t-test was used to compare the mean values of HR,  $VO_2$ ,  $VCO_2$ , VE and RER between the two LV-HIIT protocols. Cohen’s  $d_z$  was used to determine the effect size (ES) of the mean difference (Hopkins et al., 2009). Two-way repeated-measures ANOVA (protocol by time) was used to compare physiological variables (i.e. HR,  $VO_2$ ,  $VCO_2$ , VE, RER) and RPE, and affect at the equivalent times (i.e., 20%, 40%, 60%, 80%, and 100%) between two LV-HIIT protocols. In the case of a sphericity assumption violation, the degrees of freedom were adjusted and reported using the Greenhouse-Geisser epsilon correction. The Bonferroni post hoc test was used to identify significant differences when necessary. The significance level was set at  $p < 0.05$  for all analyzes. Partial eta-squared ( $\eta^2_p$ ) was used to determine the ES of the variance. All data were analyzed using SPSS version 22.0 for Windows (Statistical Package for Social Sciences, Chicago, IL, USA).

## Results

### Intensity of LV-HIIT sessions

A total of 10 men completed the study, but one participant performed only eight intervals in the 60/60 s LV-HIIT protocol due fatigue. As expected, due the matched mean load ( $V_{\text{mean}}$ ,  $8.2 \pm 0.9$  km/h), the energy expenditure of 60/60 s and 30/30 s LV-HIIT protocols were similar ( $263.5 \pm 57.3$  kcal vs.,  $250.7 \pm 45.9$  kcal,  $p = 0.06$ , respectively). The average  $\%VO_{2\text{peak}}$  of intervals was higher at 60/60 s LV-HIIT protocol than to the 30/30 s LV-HIIT protocol ( $87.0 \pm 6.4$  vs.  $75.6 \pm 6.0$  %;  $p < 0.001$ ;  $ES = 3.47$ ) while average  $\%VO_{2\text{peak}}$  at recovery periods was lower at 60/60 s LV-HIIT protocol ( $49.6 \pm 6.8$  vs.  $63.5 \pm 4.8$  %;  $p < 0.001$ ;  $ES = 2.35$ ). However, the average  $\%VO_{2\text{peak}}$  of protocols (i.e. including interval and recovery periods) was similar

between the 60/60 s and 30/30 s LV-HIIT protocols ( $68.3 \pm 6.1$  vs.  $69.6 \pm 4.9$  %;  $p = 0.308$ ).

The average HR ( $91.1 \pm 3.5$  vs.  $88.4 \pm 4.3$  %HR<sub>max</sub>;  $p = 0.001$ ; ES = 1.52) was slightly higher at intervals of the 60/60 s LV-HIIT protocol and it was lower at recovery periods ( $71.4 \pm 6.8$  vs.  $82.2 \pm 6.2$  %HR<sub>max</sub>;  $p = 0.002$ ; ES = 1.34). However, the protocols average HR (i.e. including the intervals and recovery periods) was slightly lower during the 60/60 s LV-HIIT protocol ( $82.3 \pm 4.9$  vs.  $85.8 \pm 5.4$  %HR<sub>max</sub>;  $p = 0.049$ ; ES = 0.72).

### Mean physiological responses to LV-HIIT sessions

Table 1 describes the average absolute values of VO<sub>2</sub>, VCO<sub>2</sub>, VE, and RER during both protocols. VO<sub>2</sub> and VCO<sub>2</sub> were higher at intervals of the 60/60 s LV-HIIT protocol ( $p \leq 0.011$ ), but lower during the recovery periods ( $p \leq 0.022$ ) than to the 30/30 s LV-HIIT protocol. The opposite pattern was observed for RER; i.e. lower values during the intervals of 60/60 s LV-HIIT protocol ( $p = 0.005$ ), but higher values during the recovery periods compared to the 30/30 s LV-HIIT protocol ( $p < 0.001$ ). VE was higher at intervals of the 60/60 s LV-HIIT protocol ( $p < 0.001$ ), but similar between protocols during the recovery periods. Regarding the mean overall strain (i.e. including the intervals and recovery periods), the VO<sub>2</sub>, VCO<sub>2</sub> and VE were similar between the two LV-HIIT sessions, while the RER was higher during the 60/60 s LV-HIIT than to the 30/30 s LV-HIIT ( $p = 0.003$ ).

### Physiological responses at the equivalent times

Regarding the physiological responses over the two LV-HIIT sessions in the intervals and recovery periods at the equivalent times (i.e. 20%, 40%, 60%, 80%, and 100%), there was a protocol by time interaction for %VO<sub>2peak</sub> at intervals ( $F_{(4, 32)} = 5.115$ ,  $p = 0.003$ ;  $\eta^2_p = 0.39$ ) and recovery periods ( $F_{(4, 36)} = 4.615$ ,  $p = 0.005$ ;  $\eta^2_p = 0.37$ ). The %VO<sub>2peak</sub> was higher in the intervals ( $F_{(1, 8)} = 57.252$ ,  $p < 0.001$ ;  $\eta^2_p = 0.87$ ) and lower in the recovery periods ( $F_{(1, 8)} = 60.833$ ,  $p < 0.001$ ;  $\eta^2_p = 0.88$ ) for 60/60 s LV-HIIT in all equivalent times. During the intervals of the 60/60 s LV-HIIT session the %VO<sub>2peak</sub> varied from  $82.2 \pm 7.2$  to  $92.4 \pm 7.7$ % and during the recovery periods from  $46.0 \pm 5.4$  to  $51.8 \pm 8.3$ %. During the intervals of the 30/30 s LV-HIIT session the %VO<sub>2peak</sub> varied from  $74.0 \pm 7.5$  to  $79.4 \pm 5.4$ %

and during the recovery periods from  $63.3 \pm 4.7$  to  $61.6 \pm 5.2$ %.

There was no protocol by time interaction for %HR<sub>max</sub> in the intervals ( $F_{(4, 36)} = 2.552$ ,  $p = 0.056$ ;  $\eta^2_p = 0.22$ ) and recovery periods ( $F_{(4, 36)} = 0.516$ ,  $p = 0.724$ ;  $\eta^2_p = 0.05$ ). There was only a main effect of time for intervals ( $F_{(4, 36)} = 28.993$ ,  $p < 0.001$ ;  $\eta^2_p = 0.76$ ) and recovery periods ( $F_{(4, 36)} = 22.439$ ,  $p < 0.001$ ;  $\eta^2_p = 0.71$ ). %HR<sub>max</sub> of intervals in the 60/60 s LV-HIIT session varied from  $88.0 \pm 4.5$  to  $96.8 \pm 3.7$ % and during the recovery periods from  $67.8 \pm 4.7$  to  $76.7 \pm 6.3$ %, while the intervals of 30/30 s LV-HIIT session, the %HR<sub>max</sub> varied from  $88.4 \pm 4.7$  to  $94.6 \pm 3.4$ % and during the recovery periods from  $78.7 \pm 3.9$  to  $87.0 \pm 4.4$ %.

Figure 2 shows the absolute values of VO<sub>2</sub>, VCO<sub>2</sub>, VE, and RER over both LV-HIIT sessions at the equivalent times. VO<sub>2</sub> was higher during the intervals ( $F_{(4, 32)} = 5.384$ ,  $p = 0.002$ ;  $\eta^2_p = 0.40$ ) and lower during the recovery periods ( $F_{(4, 32)} = 4.542$ ,  $p = 0.005$ ;  $\eta^2_p = 0.36$ ) in all equivalent times for 60/60 s LV-HIIT session. For VCO<sub>2</sub>, there was only a main effect of protocol during intervals ( $F_{(1, 8)} = 10.687$ ,  $p = 0.011$ ;  $\eta^2_p = 0.57$ ) and recovery periods ( $F_{(1, 8)} = 9.878$ ,  $p = 0.014$ ;  $\eta^2_p = 0.55$ ). VCO<sub>2</sub> was higher during the intervals and lower at recovery periods for 60/60 s LV-HIIT session. VE was higher during the intervals in all equivalent times for 60/60 s LV-HIIT session ( $F_{(4, 32)} = 10.192$ ,  $p < 0.001$ ;  $\eta^2_p = 0.56$ ). For RER, there was only a main effect of protocol during intervals ( $F_{(1, 8)} = 10.539$ ,  $p = 0.012$ ;  $\eta^2_p = 0.57$ ) and protocol by time interaction in the recovery periods ( $F_{(4, 32)} = 7.257$ ,  $p < 0.001$ ;  $\eta^2_p = 0.48$ ). RER was higher during the recovery periods in all time points for 60/60 s LV-HIIT session.

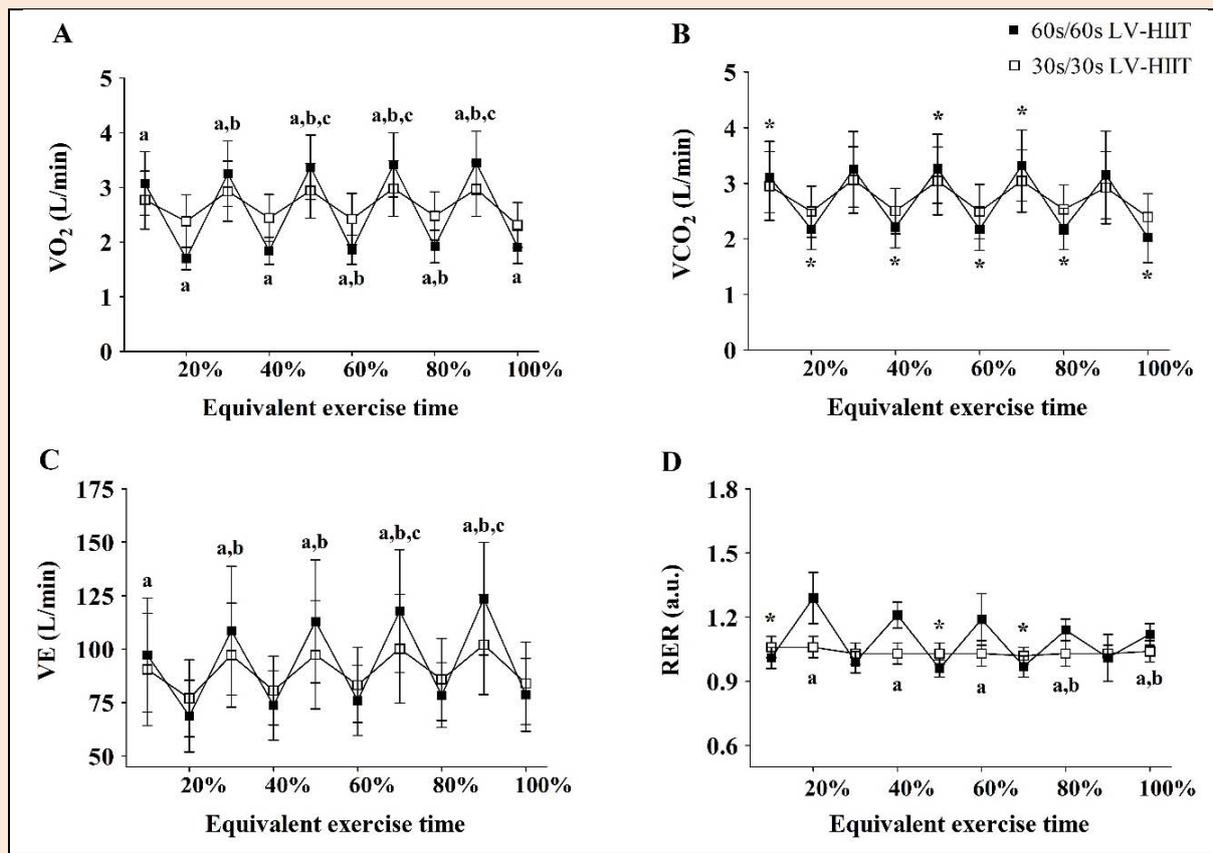
### Mean affective response and RPE to LV-HIIT sessions

Table 2 describes the mean values of RPE and affect during both LV-HIIT sessions. RPE was higher during the intervals of the 60/60 s LV-HIIT session ( $p = 0.003$ ), but similar in the recovery periods between the sessions ( $p = 0.054$ ). Regarding the whole protocol analysis, RPE was higher ( $p = 0.002$ ) in the 60/60 s LV-HIIT session. The average affect was negative during intervals and whole protocol (i.e. including the intervals and recovery periods) in the 60/60 s LV-HIIT session and statistically different from the average affect positive in the 30/30 s LV-HIIT session.

**Table 1.** Mean absolute values of oxygen uptake, carbon dioxide output, ventilation, and respiratory exchange ratio during the 60/60 s and the 30/30 s LV-HIIT protocols.

		60/60 s	30/30 s	p	ES
VO <sub>2</sub> (L/min)	Interval	3.25 ± 0.57	2.83 ± 0.50	< 0.001	3.08
	Recovery	1.85 ± 0.27	2.38 ± 0.46	< 0.001	1.95
	Protocol	2.55 ± 0.40	2.61 ± 0.47	0.239	0.44
VCO <sub>2</sub> (L/min)	Interval	3.15 ± 0.61	2.93 ± 0.58	0.011	1.09
	Recovery	2.15 ± 0.35	2.44 ± 0.45	0.022	0.93
	Protocol	2.65 ± 0.45	2.69 ± 0.51	0.624	0.18
VE (L/min)	Interval	108.59 ± 27.39	94.28 ± 24.98	< 0.001	1.88
	Recovery	74.78 ± 15.96	80.50 ± 18.07	0.100	0.62
	Protocol	91.69 ± 21.16	87.39 ± 21.42	0.102	0.46
RER (a.u.)	Interval	0.98 ± 0.05	1.03 ± 0.03	0.005	1.28
	Recovery	1.20 ± 0.05	1.03 ± 0.05	< 0.001	2.49
	Protocol	1.09 ± 0.05	1.03 ± 0.03	0.003	1.53

Values are presented as mean ± SD. LV-HIIT, low-volume high-intensity interval training; VO<sub>2</sub>, oxygen uptake; VCO<sub>2</sub>, carbon dioxide output; VE, ventilation; RER, respiratory exchange ratio; ES, effect size (Cohen's d); ES < 0.2 reflects a trivial effect, ≥ 0.2 and < 0.6 reflects a small effect, ≥ 0.6 and < 1.2 reflects a moderate effect, ≥ 1.2 and < 2.0 reflects a large effect, ≥ 2.0 and < 4.0 reflects a very large effect, and ≥ 4.0 reflects a nearly perfect effect.



**Figure 2.** Oxygen uptake (VO<sub>2</sub>, panel A), carbon dioxide output (VCO<sub>2</sub>, panel B), ventilation (VE, panel C), and respiratory exchange ratio (RER, panel D) responses during the 30/30 s and the 60/60 s low-volume high-intensity interval training (LV-HIIT) protocols. Values are presented as mean ± SD. (a) difference between LV-HIIT protocols to the same time point. (b) difference intra-60/60 s LV-HIIT protocol related to the first time point. (c) difference intra-30/30 s LV-HIIT protocol related to the first time point. (\*) compared to the same time point of the 30/30 s LV-HIIT protocol, main effect of protocol by ANOVA.

**Table 2.** Mean rating of perceived exertion and affect during the 60/60 s and the 30/30 s LV-HIIT protocols.

		60/60 s	30/30 s	p	ES
RPE (6 to 20)	Interval	15.9 ± 1.5	13.9 ± 1.5	0.003	1.33
	Recovery	13.2 ± 1.8	12.3 ± 1.4	0.054	0.68
	Protocol	14.5 ± 1.4	13.1 ± 1.4	0.002	1.28
Affect (-5 to +5)	Interval	-0.8 ± 1.4	1.1 ± 2.0	0.007	0.70
	Recovery	0.6 ± 1.7	1.7 ± 1.8	0.029	0.82
	Protocol	-0.1 ± 1.4	1.4 ± 1.9	0.008	1.08

Values are presented as mean ± SD; LV-HIIT, low-volume high-intensity interval training; RPE, rating of perceived exertion; RER, respiratory exchange ratio; ES, effect size (Cohen's d<sub>z</sub>); ES < 0.2 reflects a trivial effect, ≥ 0.2 and < 0.6 reflects a small effect, ≥ 0.6 and < 1.2 reflects a moderate effect, ≥ 1.2 and < 2.0 reflects a large effect, ≥ 2.0 and < 4.0 reflects a very large effect, and ≥ 4.0 reflects a nearly perfect effect.

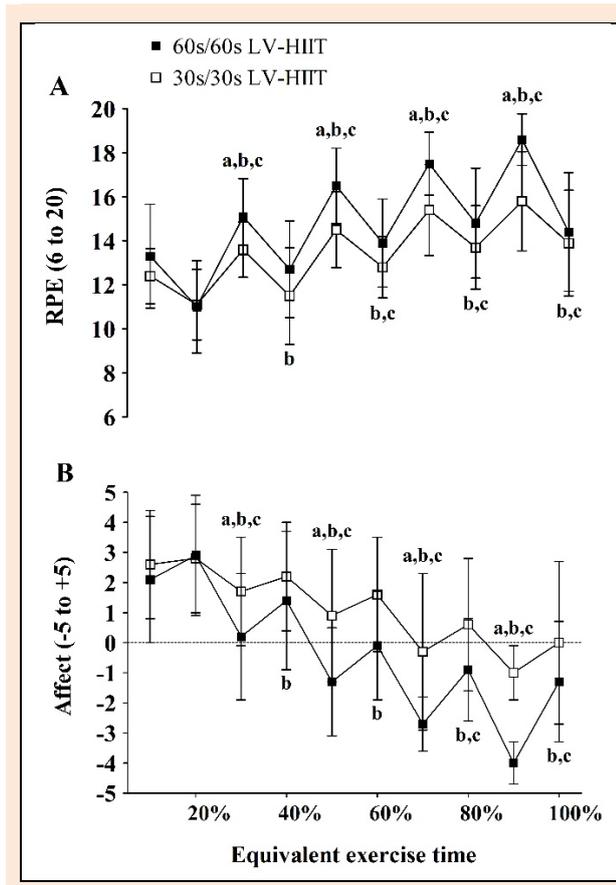
**RPE and affective response at the equivalent times**

Figure 3 shows the values of RPE and affect over both LV-HIIT sessions at the equivalent times. There was a protocol by time interaction for RPE ( $F_{(4, 36)} = 5.752, p = 0.001; \eta^2_p = 0.39$ ) and affect ( $F_{(4, 36)} = 6.461, p = 0.001; \eta^2_p = 0.42$ ) during the intervals. RPE was higher and affect was lower ( $0.2 \pm 2.1; -1.3 \pm 1.8; -2.7 \pm 0.9; -4.0 \pm 0.7$  vs.  $1.7 \pm 1.8; 0.9 \pm 2.2; -0.3 \pm 2.6; -1.1 \pm 2.8$ ) during the intervals from time points 40% until 100% of the equivalent times in the 60/60 s LV-HIIT session. During the recovery periods, there was only a main effect of time for RPE ( $F_{(4, 36)} = 23.712, p < 0.001; \eta^2_p = 0.76$ ) and affect ( $F_{(4, 36)} = 31.944, p < 0.001; \eta^2_p = 0.78$ ), there was no difference between LV-HIIT sessions.

**Discussion**

The main finding of this study was that the 30/30 s LV-HIIT protocol elicited lower rise in the physiological responses (i.e. VO<sub>2</sub>, VCO<sub>2</sub>, VE, and RPE) and an attenuated negative affective response compared to the 60/60 s LV-HIIT. These findings confirm our hypothesis that a LV-HIIT protocol with shorter work-recovery duration elicits lower physiological response and a more psychologically favorable affective response when the work-recovery ratio and the total work performed are matched.

Our results demonstrate that performing a LV-HIIT session with intervals at a fixed intensity of 100% of V<sub>max</sub> interspaced with passive recovery produces a mean



**Figure 3.** Rating of perceived exertion (RPE, panel A) and affect (panel B) responses during the 30/30 s and the 60/60 s low-volume high-intensity interval training (LV-HIIT) protocols. Values are presented as mean  $\pm$  SD. (a) difference between LV-HIIT protocols to the same time point. (b) difference intra-60/60 s LV-HIIT protocol related to the first time point. (c) difference intra-30/30 s LV-HIIT protocol related to the first time point.

intensity of  $\sim 70\%$  of  $VO_{2peak}$ , regardless of the work-recovery duration being 30 s or 60 s. However, the 60/60 s LV-HIIT protocol elicited greater amplitude (i.e. work-recovery differences) in the physiological responses ( $VO_2$ ,  $VCO_2$ , VE, RER, and RPE). For example, the work-recovery amplitude of the  $VO_2$  responses was  $\sim 37\%$  ( $\sim 87\%$  and  $\sim 50\%$  of  $VO_{2peak}$  during the interval and recovery periods, respectively) in the 60/60 s LV-HIIT protocol and  $\sim 11\%$  ( $\sim 75\%$  and  $\sim 64\%$  of  $VO_{2peak}$  during the interval and recovery periods, respectively) in the 30/30 s LV-HIIT protocol. This pattern of response shows that the duration of the interval and recovery periods influences the amplitude of physiological responses when the work-recovery ratio (1:1), the mean workload (50% of  $V_{max}$ ) and the total work performed (10 minutes) are matched. Further, as both protocols were performed at 100%  $V_{max}$  (i.e. above respiratory compensation point) the metabolic response (i.e. lactate production and clearance) probably was also influenced by the duration of intervals. Previous studies have demonstrated that the combination of duration of intervals and intensity in the interval training increases the blood lactate concentration (Tschakert and Hofmann, 2013; Tschakert et al., 2015). Therefore, our findings demonstrate that the difference of 30 s in the duration of intervals between 60/60 and 30/30 s protocols impacts the physiological responses

to LV-HIIT.

Another important difference between protocols was that the RER was lower during the interval periods in the 60/60 s LV-HIIT protocol compared to 30/30 s LV-HIIT protocol. Our finding is different from those previously reported (Tschakert et al., 2015; Tucker et al., 2015). However, it is possible that the HIIT protocol used has influenced this response (Tschakert et al., 2015; Tucker et al., 2015). Higher RER values in the recovery periods observed in the 60/60 s LV-HIIT protocol compared to 30/30 s LV-HIIT protocol suggests higher metabolic imbalance (i.e. higher lactate production than clearance), despite the lower  $VCO_2$  values observed in the end of recovery period. Additionally, RER decreases during the long recovery periods indicating the inhibition of glycolysis due to high lactate levels since the first interval, as previously demonstrated by Tschakert et al., 2015. These responses in the recovery periods seems to be a consequence of buffering the acidosis conditions from the previous interval that keep  $CO_2$  production elevated in the muscles, resulting in reduced plasma pH and hyperventilation (Peronnet and Aguilaniu, 2006), which occurs concomitant with a reduced  $O_2$  uptake due to passive recovery. In this sense, it is reasonable to speculate that the 30/30 s LV-HIIT protocol produce a lower intramuscular metabolic stress, as previously demonstrated by attenuated magnitude of intramuscular metabolic fluctuations during intermittent exercise performed with shorter work and recovery durations but performed with same external power (Davies et al., 2017). Moreover, Tschakert et al. 2015 have demonstrated that shorter intervals (i.e. 20 s) present a lactate steady state and aerobic condition compared to longer intervals (i.e. 240 s).

This finding highlights that intermittent work interval with longer duration is more dependent of anaerobic glycolysis and oxygen sources and less of PCr break-down for ATP production, causing greater intramuscular metabolic perturbation (Davies et al., 2017). In this sense, although the LV-HIIT protocols were performed at the same mean load, the intervals of 60 s seem to elicit a higher metabolic imbalance, which may influence the affective and perceptual responses. Moreover, others studies have reported that a longer HIIT protocol (4 x 240 s at 90-95% of  $HR_{max}$ ) produced greater cardiorespiratory responses during the intervals than shorter HIIT protocols (16 x 60 s at 90-95% of  $HR_{max}$  and  $\sim 30$  x 20 s at 100% of  $W_{max}$ ) (Tschakert et al., 2015; Tucker et al., 2015). Taken together, these findings reinforce that the magnitude of the physiological responses to intermittent exercise, as observed by the increase in the  $VO_2$  and  $VCO_2$  responses (Gaesser and Poole, 1996), is work and recovery time-dependent. Therefore, our results suggest that the 60/60 s LV-HIIT protocol elicits higher cardiorespiratory and intramuscular metabolic stress than the 30/30 s LV-HIIT protocol.

It should be noted that both LV-HIIT protocols reached an intensity  $\geq 80\%$  of  $HR_{max}$  (Weston et al., 2014). However, the mean intensity of the intervals was  $\sim 87\%$  and  $76\%$  of  $VO_{2peak}$  during the 60/60 s and 30/30 s LV-HIIT protocol, respectively. In this context, Buchheit and Laursen (2013) stated that the effectiveness of HR for controlling or adjusting the intensity of a HIIT session may be

limited. The HR lag at exercise onset, which is much slower to respond compared with the  $\text{VO}_2$  response, is responsible for the inaccuracy of HR in determining the energy contribution during HIIT protocols that adopt effort intensities associated with  $\text{VO}_{2\text{max}}$ , especially for very short (< 30s) (Midgley et al., 2007) and medium-long (i.e. 1-2 minutes) (Seiler et al., 2005) intervals. Thus, the temporal dissociation between HR, energy drive and work output during HIIT, limits the ability to accurately estimate the intensity during HIIT sessions using HR alone (Buchheit and Laursen, 2013).

Despite both LV-HIIT protocols elicit a HR and  $\text{VO}_2$  responses corresponding to a vigorous intensity (i.e. 77-95% of  $\text{HR}_{\text{max}}$  and 64-90% of  $\text{VO}_{2\text{peak}}$ ) (Garber et al., 2011), the difference in the  $\text{VO}_2$  responses between the protocols should be considered. The intensity has an important role to mediate acute mitochondria-related responses to exercise (MacInnis and Gibala, 2017). Thus, it is reasonable to think that the 60/60 s LV-HIIT protocol produces higher metabolic stress (i.e. acidosis) that may result in greater metabolic signal from the activation of kinases associated with greater expression of mRNA for PGC-1 $\alpha$ , a major regulator of mitochondrial biogenesis (Egan et al., 2010). Thus, the higher percentage of  $\text{VO}_{2\text{peak}}$  achieved and the greater intramuscular metabolic perturbation suggested by higher RER values during recovery periods in the 60/60 s LV-HIIT protocol compared to the 30/30 s LV-HIIT protocol may generate greater PGC-1 $\alpha$  mRNA response (Fiorenza et al., 2018), consequentially, resulting in greater improvements in cardiorespiratory fitness, which is an independent predictor of cardiovascular health (Vigen et al., 2012). However, future studies should test this hypothesis.

Regarding the RPE, which is the perception of how hard the individual is working, its pattern of response was similar to that observed for the physiological markers of the exercise intensity (i.e.  $\text{VO}_2$ ,  $\text{VCO}_2$ , and VE); i.e. the RPE responses were higher during the 60/60 s LV-HIIT protocol compared to the 30/30 s LV-HIIT protocol. The RPE responses over the 60/60 s LV-HIIT protocol varied from “somewhat hard” in the first intervals to “very, very hard” in the last intervals. The RPE responses over the 30/30 s LV-HIIT protocol varied from “somewhat hard” in the first intervals to “very hard” in the last intervals (Borg, 1998). According to the global explanatory model of perceived exertion, the  $\text{VO}_2$ , VE, and metabolic acidosis are exercise-induced physiological signals that shape the RPE responses during exercise (Robertson and Noble, 1997). Our findings suggest that the 60/60 s HIIT protocol induced a higher cardiorespiratory and intramuscular metabolic stress to the participants as observed by the higher  $\text{VO}_2$ ,  $\text{VCO}_2$ , VE, and RER, which in turn elicited higher RPE responses compared to the 30/30 s HIIT protocol. This finding is important given that the RPE is an important predictor of the affective response during continuous and interval training sessions (Ramalho Oliveira et al., 2015). In addition, RPE is negatively correlated with affective response, regardless of the individuals’ physical activity status (i.e. active or inactive) (Frazao et al., 2016). Therefore, strength and conditioning coaches should consider the RPE

responses during a LV-HIIT session and its implications for the monitoring of exercise-induced cardiorespiratory and metabolic stress and affective response.

In recent years, the American College of Sports Medicine has endorsed that pleasant and enjoyable exercise can improve adoption and adherence to prescribed exercise programs and the use of tools to measure perceived pleasure during prescribed exercise should be considered (Garber et al., 2011). Our findings showed that the 30/30 s LV-HIIT protocol induced attenuated negative affective response throughout the exercise session and may be a less aversive or unpleasant LV-HIIT design because lower exercise-induced physiological and metabolic stress compared to the 60/60 s LV-HIIT protocol. During 30/30 s LV-HIIT protocol, the affective remained positive up to 60% of the exercise session (i.e. 12<sup>th</sup> interval; total work at high-intensity = 6 minutes) while only up to 40% of the exercise session in the 60/60 s LV-HIIT protocol (i.e. 4<sup>th</sup> interval; total work at high-intensity = 4 minutes). This finding reinforces that affective response is dependent of the number of intervals performed (Frazao et al., 2016), as well as of the work-recovery duration during intermittent exercise. It should be noted that less negative affective response to the 30/30 s LV-HIIT protocol could be associated to lower internal load induced by shorter protocol, as observed by the lower values of  $\text{VO}_2$ ,  $\text{VCO}_2$ , VE, RER, and RPE. Previous studies showed that HIIT protocols consisting of interval duration higher than 60 s performed at an intensity superior to 85% of  $\text{HR}_{\text{max}}$  elicit negative affective response (Frazao et al., 2016; Olney et al., 2018; Jung et al., 2014; Thum et al., 2017), which is consistent with our findings.

Moreover, we have demonstrated that affective response to 60/60 s LV-HIIT is negatively correlated with time spent above respiratory compensation point, especially in the end of the exercise session (i.e. intervals 8-10) (Farias-Junior et al., 2018). Therefore, from a psychological perspective, perform the 30/30 s LV-HIIT can be more favorable to adoption and adherence to HIIT program, especially in the first training sessions. In addition, alternative HIIT designs involving intervals at lower intensities (i.e. < 100% of  $\text{V}_{\text{max}}$ ), fewer number of intervals, longer recovery periods (i.e. > 60 s), and/or different work-recovery ratios (i.e. 1:2 or 1:3) should be considered to improve affective and perceptual responses. Despite the interesting findings observed in our study, the absence of blood lactate concentration measures is an important limitation to assess the acute metabolic response to different HIIT protocols and its relationship with perceived exertion and affective responses.

## Conclusion

Shorter work-recovery duration elicits lower physiological response and attenuated negative affective response when LV-HIIT sessions are matched by work-recovery ratio and total work performed. From a practical perspective, LV-HIIT protocols with shorter work-recovery duration (e.g. 30/30 s) should be considered for inactive individuals and active individuals without experience in HIIT. LV-HIIT protocols with longer work-recovery duration (e.g. 60/60

s) should be considered as a progression of a HIIT program as well as for more active individuals. Further, future studies should investigate whether physiological and fitness changes as well as affective responses and adherence rates during LV-HIIT regimens with different work-recovery durations are also dissimilar.

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### Key points

- LV-HIIT protocol with shorter work-recovery duration elicited lower rise in the physiological responses.
- Intervals at a fixed intensity of 100%  $V_{max}$  interspaced passive recovery produces a mean intensity of ~70% of  $VO_{2peak}$ , but LV-HIIT with longer duration elicited greater amplitude (i.e. work-recovery differences) in the physiological responses ( $VO_2$ ,  $VCO_2$ , VE, RER, and RPE).
- LV-HIIT protocol with shorter work-recovery duration elicited an attenuated negative affective response compared to longer.

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