

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Physiological, perceptual and affective responses to high-intensity interval training using two work-matched programs with different bout duration in obese males

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ARTICLE INFO

Article history:

Received 31 January 2022

Received in revised form

6 April 2022

Accepted 7 April 2022

Available online 11 April 2022

Keywords:

Enjoyment

High-intensity interval training (HIIT)

Obesity

Perceptual responses

Pleasure-displeasure

ABSTRACT

Objectives: This study compared physiological, perceptual, and affective responses to high-intensity interval training (HIIT) between two work-matched programs with different bout durations in obese males. **Methods:** Sixteen low-to-moderately active obese men completed an eight-week cycling program of supervised HIIT (3 days/week) using either short bouts [48 × 10 s at 100% of peak power output (PPO) with 15 s of recovery (HIIT10)] or long bouts [8 × 60 s at 100% PPO with 90 s of recovery (HIIT60)]. Workload was progressively adjusted, to maintain high intensity (100% PPO), throughout training. Blood lactate (BLa), heart rate (HR), ratings of perceived exertion (RPE), and feeling scale ratings (pleasure/displeasure) were measured in each HIIT session.

Results: Average HR decreased in the last 2 weeks of training in both groups by $2.2 \pm 1.8\%$ of peak HR ($p < 0.001$). Training resulted in a reduction in BLa during exercise by $28 \pm 19\%$ ($p < 0.001$) from the 10th min onward only in HIIT10. Similarly, during the last weeks of training, RPE decreased (by 1.0 ± 1.1 units, $p < 0.05$) and feeling scale ratings were improved only in HIIT10, while RPE remained unchanged and feeling scale ratings deteriorated in HIIT60 (from 3.0 ± 1.1 to 2.1 ± 0.9 units, $p < 0.001$). No differences in post-exercise enjoyment were found.

Conclusion: Both HIIT formats induced similar HR adaptations, but improvement of BLa, perceptual and affective responses occurred only when bout duration was shorter. Our findings suggest that, in low-to-moderately active obese men, HIIT may be more effective in improving metabolic, perceptual, and affective responses when shorter, rather than longer, bouts of exercise are used.

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<https://doi.org/10.1016/j.jesf.2022.04.002>

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1. Introduction

Regular exercise constitutes an important lifestyle intervention for preventing and managing chronic diseases such as type 2 diabetes, cancer and obesity.¹ Obesity, in particular, is associated with high incidence of comorbidities² and increased all-cause mortality.³ In most cases, obesity is accompanied by physical inactivity, and surveys show that participants with higher body mass index

(BMI) engage in less physical activity compared with normal-weight individuals.^{4,5} Among the most frequently reported barriers to physical activity in obese adult individuals are lack of time and lack of enjoyment.⁶

During the past two decades, high-intensity interval training (HIIT) has been received as suitable and effective alternative to moderate-intensity continuous training for populations with sedentary lifestyle,⁷ as it brings about significant cardiometabolic health benefits with less time commitment.^{8,9} However, HIIT has attracted some criticisms, with the main one being, that it causes negative affective responses (i.e., feelings of displeasure) during exercise.^{10,11} According to the “dual-mode model,”¹² exercising at an intensity above a certain “threshold”, e.g., lactate threshold or critical velocity, induces high ratings of perceived exertion (RPE) and negative affective responses, especially in inactive obese individuals, leading to low exercise adherence.^{13,14} In contrast, there is evidence that the intermittent nature of HIIT promotes positive affective responses (i.e., perceived enjoyment), which promotes exercise adherence.^{11,15,16} Inactive overweight and obese adults exert more effort^{17–19} and report less positive feelings^{17,20} during HIIT compared to moderate-intensity continuous training, but they experience similar post-exercise enjoyment levels independent of exercise modality.^{17–20}

Despite the worldwide popularity of HIIT as a fitness trend,²¹ comparison of perceptual responses to different HIIT formats is largely limited to acute studies.^{22–25} Among the characteristics of a HIIT program, exercise bout duration appears to modulate not only physiological and metabolic responses,^{26,27} but also psychological aspects such as pleasure and enjoyment.^{22–25} Thus, when exercise intensity was within the severe domain, longer (120 s) rather than shorter bouts (30 and 60 s) resulted in higher RPE, as well as less positive post-exercise affective and enjoyment responses.^{23,24} In addition, anaerobic glycolysis contributes less during shorter vs. longer bouts of HIIT despite equal total work.^{25,28} Nevertheless, the long-term effects of bout duration during HIIT are largely unknown, especially in overweight/obese populations whose exercise enjoyment and adherence may be more sensitive to metabolic stress.^{29–31} Therefore, the purpose of the present study was to investigate the effects of 2 months of HIIT, using two programs of equal total work but different bout duration (10 s and 60 s), on physiological, perceptual and affective responses in low-to-moderately active obese adult males. Changes in fat oxidation during submaximal exercise and regional body composition following these protocols have been previously published.³²

2. Methods

2.1. Participants

Power analysis using repeated-measures within-between interaction analysis of variance (G-Power software, v. 3.1.9.2, Universität Kiel, Kiel, Germany) indicated a minimum sample size of 6 participants per group, based on a power of 0.80, alpha of 0.05, and correlation coefficient of 0.5 between repeated measures. In relevant studies^{29,33} the effect size regarding perceptual, affective and heart rate responses ranged between medium and large (η^2 values reported were between 0.11 and 0.21). We therefore opted to use a medium effect size in the a priori power analysis for all parameters examined ($\eta^2 = 0.137$) based on Cohen (1988).³⁴

Participants were recruited via email, social networks, and notices posted in hospitals of the National and Kapodistrian University of Athens. A total of 41 individuals visited the laboratory for subsequent screening to ensure that they (a) were free of any respiratory, metabolic, and/or hematological disease or family history of premature cardiovascular death through a detailed health

history questionnaire, (b) BMI between 28 and 35 kg/m² and body fat ≥ 25 , (c) had not participated in a dietary intervention or used any nutritional supplements for the preceding 6 months, (d) were non-smokers, (e) had stable body weight (weight fluctuations of <2 kg) over the preceding 6 months, (f) had not engaged in a structured exercise program during the past 12 months and had low to moderate levels of physical activity, and (g) had medical clearance from a cardiologist. Twenty-one volunteers were excluded for not fulfilling the eligibility criteria, leaving 20 healthy low-to-moderately active obese men, aged 18 to 50, who were randomly assigned to two groups ($n = 10$ each). During the intervention two participants from each group dropped out due mainly to schedule conflicts.

The study was conducted according to the World Medical Association Declaration of Helsinki³⁵ and approved by the Aretaieion hospital Ethics Committee (B-153/4-2-2016). All participants provided written informed consent after a thorough explanation of the testing and training protocols, the risks involved and the right to withdraw at will.

2.2. Study design

Participants were subjected to an 8-week HIIT cycling program including either short (10 s, HIIT10 group) or long bouts (60 s, HIIT60 group) with equal training volume. The intensity of the work bouts was 100% of peak power output (PPO), while the intensity during recovery periods was 15% PPO. The primary outcome measures were blood lactate concentration (BLa), heart rate (HR), RPE, affective valence (pleasure-displeasure), and perceived enjoyment during exercise and Physical Activity Enjoyment Scale (PACES) during all sessions.

2.3. Baseline measurements

BMI was calculated from body mass and height, measured using a calibrated scale (Seca 888, Hamburg, Germany) and stadiometer (Seca 213, Hamburg, Germany). Peak heart rate (HR_{peak}, measured with Polar RS300, Kempele, Finland) and PPO were determined through a maximal graded test to exhaustion (8–12 min) on an electronically braked cycle ergometer (Ergo bike premium 8i, Daum, Germany) at a pedal cadence of 70 rpm. The ramp protocol began at 20–35 W and continued with increments of 20–25 W per minute until volitional exhaustion.³⁶ PPO was calculated as the power in the last fully completed step and used to set training intensities during the intervention. In the case when a participant did not complete the total duration of the last stage, PPO was calculated using the following equation:

$$\text{PPO} = W_{\text{completed}} + [(t/60) \times W_{\text{increment}}]$$

where, $W_{\text{completed}}$ = the power output of the final completed stage (W).

t = the time spent in the final, uncompleted stage (s)

60 = the duration of each stage (s)

$W_{\text{increment}}$ = the increment in power output per stage (W).

2.4. High-intensity interval training

Participants exercised on the same electronically braked cycle ergometer at a steady cadence (70 rpm), 3 times per week for 8 weeks, with at least 48 h separating sessions. All sessions were supervised by the research staff and executed under controlled environmental conditions (20–21 °C) at the same time of day

(mornings) for each participant.

Each HIIT10 session consisted of 48 10-s intervals at 100% PPO interspersed with 15 s of recovery at 15% PPO. Each HIIT60 session consisted of 8 60-s intervals at 100% PPO interspersed with 90 s of recovery at 15% PPO. All HIIT sessions lasted 20 min, preceded by 5 min of warm-up and followed by 3 min of cool-down, both at 15% PPO. In accordance with the principle of progressive overload, exercise intensity was increased by 10% PPO after 6 sessions. The load was readjusted after 12 sessions, based on a repetition of the maximal graded test. Finally, intensity was increased by 5% PPO after 18 sessions. Average work was matched for the two protocols, as described.³²

2.5. Physiological responses

Fingertip capillary blood lactate was measured every 5 min during the 1st and 24th sessions with a portable device (Lactate Scout+; EKF, Barleben, Germany). Heart rate (HR) was recorded every 5 s using the same monitor as above during all sessions. Average values were calculated every 5 min. These were further averaged every 2 weeks and expressed as a percentage of the highest HR value of the two maximal tests performed at the start and end of training (%HR_{peak}).

2.6. Perceptual and affective responses and post-exercise enjoyment

Perceived exertion was assessed via the 6–20 Borg scale.³⁷ Ratings of pleasure-displeasure (affect) were assessed using the single-item, 11-point feeling scale,³⁸ which ranges from –5 (very bad) to +5 (very good). All participants were thoroughly familiarized with the instrument procedures during preliminary visits.³² The aforementioned scales were randomly presented by the visual preference technique, and verbal responses were recorded immediately before the start of exercise and during the last 15 s of recovery intervals at 5, 10, 15, and 20 min of each session. PACES was used to evaluate enjoyment by answering 18 questions scored on a 1–7 Likert scale, 10 min following each session.³⁹ Data from these assessments were averaged every 2 weeks.

2.7. Statistical analysis

The Shapiro-Wilk and Levene's tests were used to assess normality and homogeneity of variances, respectively. Three-way mixed-model ANOVA with repeated measures (2 groups x 4 or 5 exercise time points x 2 or 4 training time points) was used to evaluate changes in BLa, HR, RPE, and feeling scale. Changes in PACES were evaluated using mixed-model two-way ANOVA (2 groups x 4 training time points). When a significant interaction or main effect was observed, Tukey's post-hoc test was used to locate significant differences between means. Effect sizes for main effects and interactions were determined by η^2 and classified as small (0.01–0.058), medium (0.059–0.137), or large (>0.137).³⁴ Data are expressed as means \pm standard deviation (SD) and analyzed using SPSS (version 23.0 IBM, Armonk). Significance was set at $p < 0.05$.

3. Results

Selected descriptive characteristics of the participants in each group at baseline are presented in Table 1. As also presented elsewhere,³² the HIIT10 and HIIT60 groups did not differ in age, anthropometric characteristics, training compliance, HRpeak, PPO, energy intake, diet composition, or physical activity. The improvement in PPO during the maximal graded test after 12 sessions, as compared with baseline, was $13.2 \pm 2.8\%$ and $12.9 \pm 3.4\%$,

Table 1

Participants' descriptive characteristics at baseline. Values are means \pm standard deviation.

Variables	HIIT10	HIIT60
Age (years)	37.2 \pm 9.5	40.2 \pm 3.9
Body mass (kg)	91.9 \pm 7.9	94.3 \pm 14.1
BMI (kg/m ²)	29.8 \pm 2.1	30.1 \pm 2.6
Total body fat (%)	31.5 \pm 4.0	32.1 \pm 3.9
VO _{2peak} (ml/kg/min)	29.4 \pm 2.4	32.5 \pm 5.0
PPO (W)	193 \pm 16	214 \pm 32

PPO, peak power output; BMI, body mass index.

$p < 0.001$, for HIIT10 and HIIT60, respectively. Similar improvements, also compared with baseline, were observed at the end of training ($19.5 \pm 2.8\%$ and $16.7 \pm 3.4\%$ $p < 0.001$, respectively). No musculoskeletal injuries or adverse events were recorded during the study period.

3.1. Blood lactate

The 3-way ANOVA for BLa revealed a group x exercise time x training time interaction ($p = 0.019$, $\eta^2 = 0.209$) and a group x training time interaction ($p = 0.027$, $\eta^2 = 0.304$). There were also main effects of group ($p < 0.001$, $\eta^2 = 0.781$), training time ($p = 0.045$, $\eta^2 = 0.257$), and exercise time ($p < 0.001$, $\eta^2 = 0.884$). Post-hoc tests revealed that BLa increased gradually during exercise in both groups ($p < 0.001$), BLa was lower in HIIT10 than HIIT60 in the first and last training sessions ($p = 0.003$ and 0.001 , respectively), and training resulted in a reduction of BLa only in HIIT10 from the 10th min of exercise onward by an average of $28 \pm 19\%$ ($p < 0.001$) but not in HIIT60 ($p = 0.997$, Fig. 1).

3.2. Heart rate

The 3-way ANOVA for HR averaged every 5 min of exercise and every 6 training sessions revealed only main effects of training time ($p < 0.001$, $\eta^2 = 0.399$) and exercise time ($p < 0.001$, $\eta^2 = 0.967$), suggesting similar HR responses to the two training protocols. Post-hoc analysis revealed that HR increased throughout exercise in both groups ($p < 0.001$) and that HR was significantly decreased at weeks 5–6 and 7–8 compared to weeks 1–2 for both HIIT60 and HIIT10 by 1.4 ± 1.5 and $2.2 \pm 1.8\%$ HRpeak ($p = 0.024$ and $p < 0.001$, respectively, Fig. 2).

3.3. Perceptual responses

RPE, measured every 5 min of exercise and averaged every 6 training sessions during the 8-week HIIT programs, are shown in Fig. 3. The 3-way ANOVA showed a group x training time interaction ($p = 0.014$, $\eta^2 = 0.222$), as well as main effects of group (RPE being lower in HIIT10, $p = 0.027$, $\eta^2 = 0.305$) and exercise time ($p < 0.001$, $\eta^2 = 0.961$). Post-hoc tests showed that RPE, increased gradually during exercise ($p < 0.001$), and decreased at weeks 5–6 and 7–8 compared to weeks 1–2 by 1.0 ± 1.1 units only in HIIT10 ($p = 0.019$ and 0.030 , respectively, Fig. 3).

3.4. Affective responses

The 3-way ANOVA for feeling scale rating, measured every 5 min of exercise and averaged every 6 training sessions, showed a significant group x training time x exercise time interaction ($p = 0.003$, $\eta^2 = 0.182$) and a main effect of exercise time ($p < 0.001$, $\eta^2 = 0.645$). Post hoc tests showed that feeling scale ratings were decreased during the last 10 min of exercise in HIIT10 only in weeks

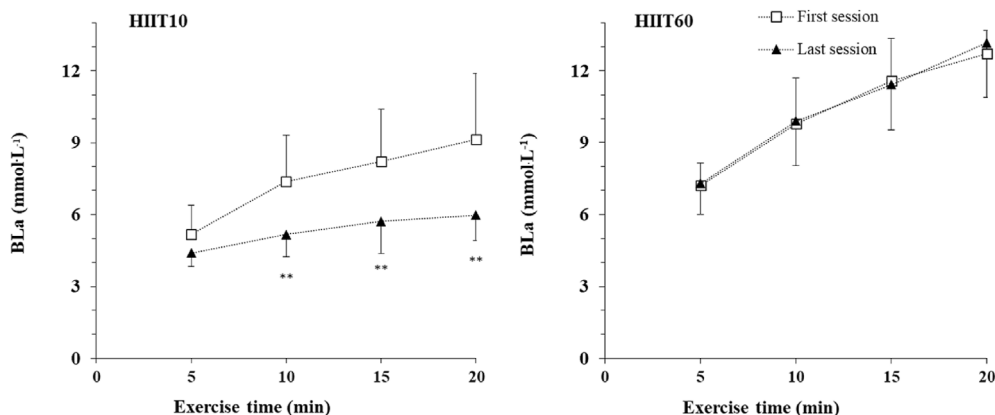


Fig. 1. Blood lactate concentration (BLa) during the first and last session of the 8-week training intervention in the HIIT10 and HIIT60 groups. **: $p < 0.01$ compared to the first session. Values are means \pm SD.

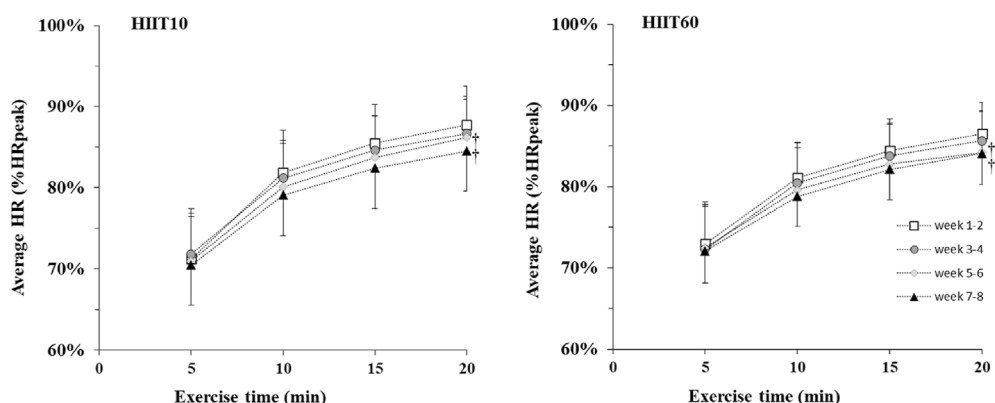


Fig. 2. Heart rate (HR) averaged every 5 min of exercise and every 6 training sessions (i.e., 2 weeks), in the HIIT10 and HIIT60 groups. †: $p < 0.01$ compared to weeks 1–2. Values are means \pm SD.

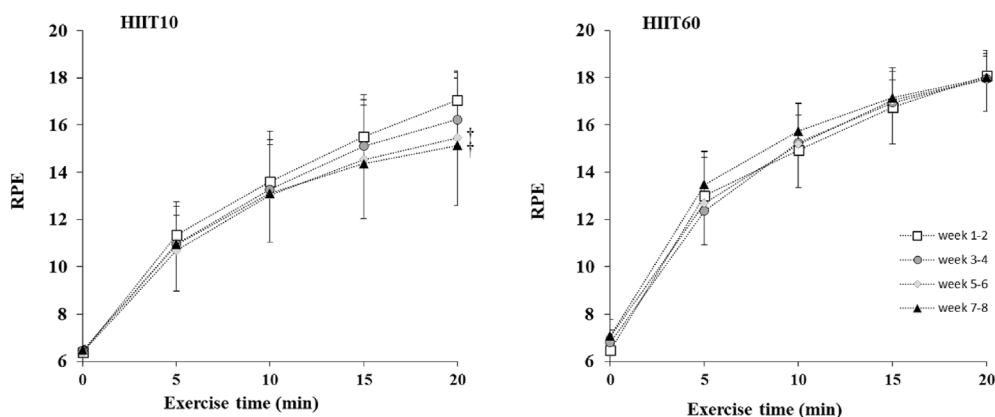


Fig. 3. Rating of perceived exertion (RPE), averaged every 6 training sessions (i.e., 2 weeks), in the HIIT10 and HIIT60 groups. †: $p < 0.05$ compared to weeks 1–2. Values are means \pm SD.

1–2 ($p < 0.001$), while they remained unaltered from baseline from weeks 3–4 until the end of training (Fig. 4). However, in HIIT60, feeling scale ratings decreased throughout exercise in all weeks of training ($p < 0.001$). Training had different effects on feeling scale ratings, with HIIT10 resulting in improved ratings and HIIT60 resulting in worse ratings (i.e., more aversive responses) in weeks 5–6 and 7–8 compared with weeks 1–2 (from 3.0 ± 1.1 units in weeks 1–2 to 2.2 ± 0.8 units in weeks 5–6, $p = 0.026$, to 2.1 ± 0.9

units in weeks 7–8, $p < 0.001$).

3.5. Post-exercise enjoyment

Responses on the PACES questionnaire after each session, averaged every 6 training sessions, are presented in Fig. 5. There was no significant group \times training time interaction or main effects of group or training.

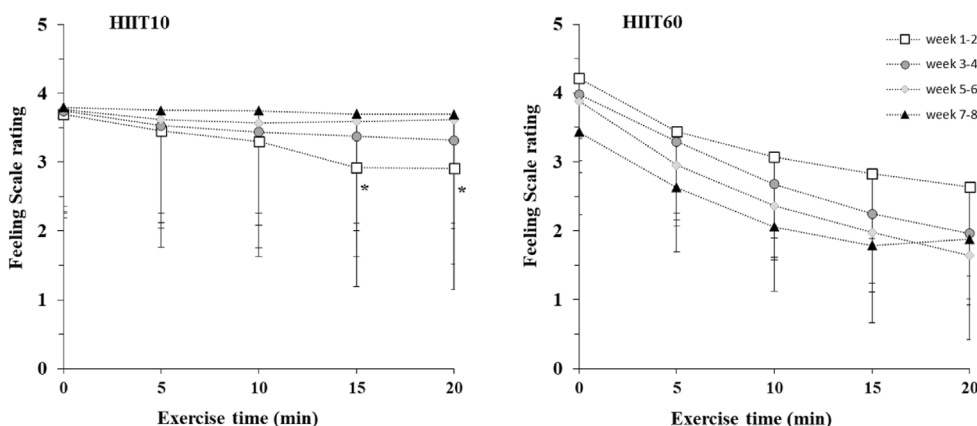


Fig. 4. Feeling scale, averaged every 6 training sessions (i.e., 2 weeks), in the HIIT10 and HIIT60 groups. *: $p < 0.05$ from the corresponding time points of weeks 5–6 and 7–8; †: $p < 0.05$ and ††: $p < 0.01$ compared to weeks 1–2. Values are means \pm SD.

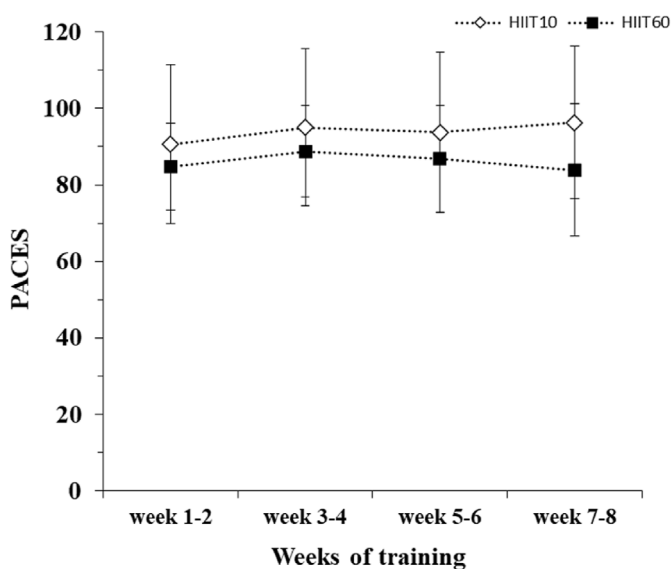


Fig. 5. Physical activity enjoyment scale (PACES) score after each training session, averaged every 6 sessions (i.e., 2 weeks), in the HIIT10 and HIIT60 groups. Values are means \pm SD.

4. Discussion

The purpose of the present study was to investigate the effects of 2 months of HIIT, using two programs of equal total work but different bout duration, on physiological and perceptual responses in low-to-moderately active obese adult males. The main finding was that metabolic (as assessed through BLA), perceptual, and affective responses to HIIT for 8 weeks in low-to-moderately active obese men were improved when bout duration was short (10 s) but not when bout duration was long (1 min) with equal exercise intensity, total work and work-to-recovery ratio. Importantly, affective responses were improved during training in the HIIT10, while, on the contrary, metabolic responses were blunted and feelings of dislike were increased in HIIT60 as training proceeded. This highlights the importance of bout duration during HIIT in obese individuals.

Both training protocols elicited a small (though highly significant and with large effect size) reduction in HR during exercise. This may be attributed to central adaptations, such as increase in stroke volume due to high HR values (80–90% HRpeak) during the last

10 min of exercise, as has been observed during HIIT in overweight individuals.⁴⁰ Similar findings have been observed in previously sedentary males following 24 sessions of HIIT (5 \times 3 min of cycling at 80% VO₂peak) and have been attributed to increased left ventricular mass.⁴¹ However, HIIT60 was characterized by higher BLA compared to HIIT10, indicating higher internal stress.

The decreased BLA response to training in HIIT10 is in accordance with the notion of decreased internal stress despite an increase in external stress due to progressive overload. Our results are in line with studies demonstrating less metabolic strain of acute short-vs. long-interval protocols of identical load and total exercise time.^{22,25} The higher BLA in HIIT60 implies higher glycolytic contribution to overall energy production,²⁶ and this may be related with the higher RPE and the more adverse affective responses. Moreover, the decrease in BLA from the first to the last training session only in HIIT10 may indicate that metabolic adaptations are facilitated by a lower BLA and hindered when BLA is higher,⁴² although some studies have shown the opposite.⁴³

Besides peripheral adaptations, intense HIIT has been associated with greater disturbances of the immune and hormonal systems.^{44,45} It may be hypothesized that HIIT60 for 8 weeks in these inactive and obese individuals caused greater immune and hormonal disturbances, indicative of overtraining, which may partly explain the lack of adaptations in BLA, the unchanged RPE, and the increase in aversive feelings observed after 8 weeks of training. This supports the need of performing HIIT in a periodized manner (i.e. to alternate easier and harder sessions) or to alternate HIIT sessions with moderate intensity exercise sessions, especially in sedentary or obese individuals.

The link between metabolic stress and perceived exertion deserves thorough examination in HIIT, as RPE and affective responses may have a considerable effect on exercise adherence.^{29,46,47} Two studies in untrained adults have examined changes in RPE with HIIT and both have found reductions.^{29,48} In the present study RPE responses to HIIT were modulated by bout duration. Our findings of a reduction in perceptual and affective responses to HIIT10 only suggest that these may be mostly driven by metabolic, rather than cardiovascular, adaptations.³⁷ Since HIIT is a means to achieve health-related physiological and metabolic adaptations,⁴⁹ it is important to utilize HIIT protocols that are well tolerated and pleasurable. Therefore, the present study suggests that shorter, as opposed to longer, bursts of cycling are well tolerated by healthy obese individuals, which may increase positive feelings during exercise and, in turn, exercise adherence.

RPE may be a key factor in determining in-task affective

valence.⁵⁰ Our study showed that, HIIT10 protocol was less strenuous (i.e. lower RPE) and induced greater feelings of pleasure after the first 4 weeks of intervention. Conversely, participants in HIIT60 showed no significant reductions of RPE combined with a decrease in pleasurable feelings from pre to post training. The decrease in feeling scale scores as training progressed in HIIT60 suggests a negative feedback of metabolic responses to feelings of pleasure during exercise according to the dual-mode theory.¹³ Although previous studies have shown that bout duration influences acute affective responses, i.e., they are more positive in 30 s vs. 60 s,²² we found no information regarding changes in affect following a period of HIIT interventions. Thus, our study is the first to demonstrate that training with longer bout duration results in a progressive decrease in affect, possibly due to the persistently high RPE and BLA, despite 8 weeks of HIIT. Previous results have shown that BLA and RPE are important mediators of in-task affect.^{51,52} However, more studies are needed to confirm this relationship.

Enjoyment is an important factor of future exercise participation.⁵³ The mean PACES score in our study is comparable with previously reported values during acute high-intensity interval exercise with bouts lasting 30–120 s.^{19,24} The current study demonstrated that the HIIT60 group experienced less positive in-task affect but similar post-exercise enjoyment compared to HIIT10. In addition, the enjoyment response to the two HIIT regimes remained high and constant during training, despite the increase in external load. The high degree of enjoyment experienced following HIIT might be explained by the nature of interval exercise, which promotes the sense of accomplishment and therefore leads to enhanced in-task efficacy feelings.⁵⁴ Similar findings have been reported for overweight/obese participants, who had comparable enjoyment levels after a 3-week HIIT intervention using either repeated 60 s or 120 s bouts at 80–100% PPO.³¹ These findings confirm the positive effects of work-matched HIIT programs on post-exercise enjoyment, independent of bout duration or work-to-recovery ratio. Nevertheless, the improved BLA, RPE, and affect after 8 weeks of training only in HIIT10 suggest a superiority of shorter bouts of HIIT regarding physiological, perceptual, and affective adaptations, possibly leading to better exercise adherence.

5. Conclusion

In obese, low-to-moderately active males, HIIT using shorter bouts (10 s) resulted in decreased BLA, RPE, and affective responses. In contrast, BLA and RPE adaptations were blunted, and affect worsened with longer bouts (60 s) despite equal total load. Our findings suggest that, in low-to-moderately active obese men, HIIT with progressive overload may be more effective in improving metabolic, perceptual, and affective responses when shorter, rather than longer, bouts of exercise are used.

Author contributions

Spryridon Tsirigkakis: Collected the data, Performed the analysis, Wrote the paper, Other contribution, Yiannis Koutedakis: Conceived and designed the analysis, Performed the analysis, Other contribution, George Mastorakos: Performed the analysis, Other contribution, Pinelopi S. Stavrinou: Performed the analysis, Wrote the paper, Other contribution: Vassilis Mougios, Conceived and designed the analysis, Other contribution: Gregory C. Bogdanis, Conceived and designed the analysis, Collected the data, Wrote the paper, Other contribution.

Funding

This work is part of the SAFE PATH (Stand up And Fight obEsity:

Promoting Aerobic Training and Health) research project and was funded by The Coca-Cola Company. This funding source had no involvement in study design, study execution, data collection, data analysis, or manuscript preparation.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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