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Comparison of affective responses during and after low volume high-intensity interval exercise, continuous moderate- and continuous high-intensity exercise in active, untrained, healthy males

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Full Title:	Comparison of affective responses during and after low volume high-intensity interval exercise, continuous moderate- and continuous high-intensity exercise in active, untrained, healthy males
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Abstract:	This study compared affective responses to low volume high-intensity interval exercise (HIIE), moderate-intensity continuous exercise (MICE) and high-intensity continuous exercise (HICE). Twelve untrained males (VO2max 48.2 ± 6.7 ml·kg-1·min-1) completed MICE (30 min cycle at 85% of ventilatory threshold (VT)), HICE (cycle at 105% of VT matched with MICE for total work), and HIIE (10 x 6 s cycle sprints with 60 s recovery). Affective valence and perceived activation were measured before exercise, post warm-up, every 20% of exercise time, and 1, 5, 10, and 15 min post-exercise. Affective valence during exercise declined by 1.75 ± 2.42, 1.17 ± 1.99, and 0.42 ± 1.38 units in HICE, HIIE, and MICE, respectively, but was not statistically influenced by trial (P = 0.35), time (P = 0.06), or interaction effect (P = 0.08). Affective valence during HICE and HIIE was consistently less positive than MICE. Affective valence post-exercise was not statistically influenced by trial (P = 0.10) and at 5 min post-exercise exceeded end-exercise values (P = 0.048). Circumplex profiles showed no negative affect in any trial. Affective responses to low volume HIIE are similar to HICE but remain positive and rebound rapidly, suggesting it may be a potential alternative exercise prescription.
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Response to Reviewers:	Reviewer #1: The revision of the paper is much improved. I have the following remarks: 1. response to Reviewer #1 point 9: new text is indicated on L388, but this doesn't seem correct. We apologise if this amendment was overlooked. We have now added this text where we believe the reviewer was referring to (P.16, L391 of anonymised manuscript). 2. response to Reviewer #1 point 17: new text is indicated on L492, but this doesn't seem correct. We believe that this amendment was made; however, we have amended the wording to make the statement clearer (P.20, L495 of anonymised manuscript). 3. Title: I recommend that the title include the statement 'active, untrained, healthy males'. Incidentally, in the paper, they are described as 'not highly trained', which seems different to me from 'untrained'. The title amendment has been made. Also, for consistency the participants are now referred to as “untrained” in the methodology. 4. L392: I would add the word 'young'

	This has been added into the location we believe the reviewer is referring to (P.16, L391 of anonymised manuscript).

Comparison of affective responses during and after low volume high-intensity interval exercise, continuous moderate- and continuous high-intensity exercise in active, untrained, healthy males

Running title: affective responses to reduced volume high-intensity interval exercise

Keywords: interval training; intermittent exercise; enjoyment; adherence

Abstract

This study compared affective responses to low volume high-intensity interval exercise (HIIE), moderate-intensity continuous exercise (MICE) and high-intensity continuous exercise (HICE). Twelve untrained males ($\dot{V}O_{2max}$ 48.2 ± 6.7 $ml \cdot kg^{-1} \cdot min^{-1}$) completed MICE (30 min cycle at 85% of ventilatory threshold (VT)), HICE (cycle at 105% of VT matched with MICE for total work), and HIIE (10 x 6 s cycle sprints with 60 s recovery). Affective valence and perceived activation were measured before exercise, post warm-up, every 20% of exercise time, and 1, 5, 10, and 15 min post-exercise. Affective valence during exercise declined by 1.75 ± 2.42, 1.17 ± 1.99, and 0.42 ± 1.38 units in HICE, HIIE, and MICE, respectively, but was not statistically influenced by trial ($P = 0.35$), time ($P = 0.06$), or interaction effect ($P = 0.08$). Affective valence during HICE and HIIE was consistently less positive than MICE. Affective valence post-exercise was not statistically influenced by trial ($P = 0.10$) and at 5 min post-exercise exceeded end-exercise values ($P = 0.048$). Circumplex profiles showed no negative affect in any trial. Affective responses to low volume HIIE are similar to HICE but remain positive and rebound rapidly, suggesting it may be a potential alternative exercise prescription.

Introduction

More than 30% of the worldwide population are insufficiently physically active for health (Hallal, 2012). Lack of time is a commonly cited barrier to completing sufficient physical activity (Aaltonen et al., 2012). Low volume high-intensity interval exercise (HIIE) is brief, repeated bursts of intense or all-out exercise separated by rest or low-intensity exercise, with total intense exercise time ≤10 min per session and total session time ≤30 min (Gillen & Gibala, 2014). Low volume HIIE can considerably improve aerobic fitness, body composition, and cardiometabolic health in a variety of populations (Babraj et al., 2009; Jakeman, Adamson, & Babraj, 2012; Tjonna et al., 2009). Therefore, low volume HIIE is a time efficient strategy for improving health and fitness (Gillen & Gibala, 2014) that may appeal to individuals with limited time to be active.

Many HIIE protocols are extremely challenging due to their high-intensity nature (Gillen & Gibala, 2014), which has led to debate around the public health value of HIIE. Several researchers have argued that individuals are unlikely to engage with, or adhere to HIIE (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014), partly because they will find it unpleasant and therefore be unlikely to repeat the experience (Rhodes & Kates, 2015). According to the dual-mode theory of affective responses to exercise (Ekkekakis, 2003), intensity is a key mediator of the affective response. Exercise above the ventilatory threshold (VT) typically leads to more unpleasant affective responses than exercise at and below VT (Astorino et al., 2016; Ekkekakis, Hall, & Petruzzello, 2008; Kilpatrick, Kraemer, Bartholomew, Acevedo, & Jarreau, 2007). However, the dual-mode theory applies to continuous exercise, and the intermittent nature of HIIE with regular recovery opportunities may allow participants to experience more positive affective responses (Jung, Bourne, & Little, 2014; Jung, Little, & Batterham, 2016).

However, an emerging body of literature suggests that HIIE generates less positive affect compared to continuous submaximal exercise (Jung et al., 2014; Oliveira, Slama, Deslandes, Furtado, & Santos, 2013; Saanijoki et al., 2015). Whilst these studies suggest that HIIE is experienced less positively compared with more moderate exercise, findings may be clouded by methodological issues. Some studies (Jung et al., 2014; Saanijoki et al., 2015) standardised continuous intensity exercise to a percentage of peak power (W_{peak}). The relative demands and tolerable duration of exercise are not adequately characterised using this approach, and instead exercise intensity domains should take account of individualised intensity thresholds, such as the VT (Mann, Lamberts, & Lambert, 2013). Additionally, the HIIE protocol used by Jung et al. (2014) was the same duration as their continuous high-intensity protocol, and the protocols of Oliveira et al. (2013), Saanijoki et al. (2015), and Decker and Ekkekakis (2016) lasted ~17-23 min, excluding warm-up and cool-down. This negates the practical attraction of reduced exercise duration with HIIE. Furthermore, the protocols adopted by Saanijoki et al. (2015) and Oliveira et al. (2013) were particularly arduous, making unclear the transferability of the findings to HIIE protocols that may be more palatable.

There has been a concerted effort to develop low volume HIIE protocols that are efficacious, time efficient, and more palatable (Gillen & Gibala, 2014). Protocols involving 20-60 s of total work within a 7-10 min exercise session can substantially improve aerobic fitness and cardiometabolic health (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, & Babraj, 2014; Allison, Martin, MacInnis, Gurd, & Gibala, 2016). However, affective responses to these protocols are not well understood. It is plausible that affective responses may be less negative than in previously reported HIIE data, due to shorter and less frequent work bouts (Jung et al., 2014; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015), and larger work-to-rest ratios implying less reliance on anaerobic metabolism relative to session duration. Recent work on the affective responses to HIIE specifically called for research to investigate affective responses to reduced volume HIIE protocols (Decker & Ekkekakis, 2016). While some research has compared affective responses to different volumes of HIIE (Martinez et al., 2015; Wood et al., 2016), a low volume HIIE protocol (i.e. 20-60 s total work) was not used.

How people feel *after* HIIE may also be of importance, as affect at the end of the task may influence future behaviour (Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993). Although in their recent review, Rhodes and Kates (2015) concluded the evidence did not support a relationship between post-exercise affect and future physical activity behaviour, this was based on only nine studies of varying quality with mixed findings, highlighting the need for further research. Further, Rhodes and Kates (2015) acknowledged the counter theoretical argument that the end of the task may be the most powerful affective stimulus (Hargreaves & Stych, 2013; Kahneman et al.). This perspective is important to investigate further because according to dual-mode theory there is likely to be a ‘rebound’ from affective negativity to positivity following exercise, regardless of intensity (Ekkekakis, 2003), and within 1 min following severe-intensity exercise (Ekkekakis, Hall, & Petruzzello, 2005b). Therefore, it is possible that affective responses post-HIIE are similar to responses following exercise at a lower intensity. Limited research has focused on affect post-HIIE with recent studies either not assessing post-exercise affect (Frazao et al., 2016; Saanijoki et al., 2015) or assessing affect at a later point (Jung et al., 2014; Oliveira et al., 2013) and potentially missing the window to document and compare the rebound effect.

The development of effective, time efficient, and palatable HIIE protocols would be an important step forward for the implementation of HIIE into public health strategies. Efficacy and time efficiency have been established; affective responses during and after these reduced volume protocols have not been well examined. The aim of this study was to compare affective responses during and after low volume HIIE, moderate-intensity continuous exercise (MICE) and high-intensity continuous exercise (HICE). We hypothesised that cardiovascular strain would be similar in the HICE and HIIE trials, and greater than the MICE trial; affective valence would decrease more during HIIE than MICE, but less than during HICE; and post-exercise affective valence would rebound within the same time-frame in all trials.

METHODS

Participants

Twelve healthy, physically active males participated (mean ± SD age 25 ± 7 years (range 19-35 years), height 177 ± 7 cm, body mass (BM) 76.5 ± 12.2 kg, maximal oxygen uptake ($\dot{V}O_{2max}$) 48.2 ± 6.7 ml·kg^{-1}·min^{-1}, W_{peak} 297 ± 36 W). Participants were generally physically active (≥ 150 min habitual physical activity per week

(National Health Service, 2013); physically active for ≥ 30 min on 5 ± 1.6 days per week (range 2-7)), untrained (below the age-gender 90th percentile for $\dot{V}O_{2max}$ (American College of Sports Medicine, 2005)), not participating in/training for a competition or event, and unfamiliar with HIIE. The sample consisted of five University staff members and seven undergraduate students (one computer science, one primary education, and five sport science students). The study was explained to participants, and written informed consent was gained. All work was conducted with the formal approval of the University of Edinburgh, Moray House School of Education Ethics Committee.

Baseline trial

All sessions took place in the same climate controlled laboratory (temperature 20-21^{o}C, relative humidity 50-55%). In visit one, anthropometric data were collected (BM: model 708; Seca, Hamburg, Germany; standing height: model 245; Seca, Hamburg, Germany), and standardised explanations of the Borg CR-10 Rating of Perceived Exertion (RPE) scale, Feeling Scale (FS, (Hardy & Rejeski, 1989)), and Felt Arousal scale (FAS, (Svebak & Murgatroyd, 1985)) were provided according to the instructions in the original publications. These explanations were briefly reviewed at the beginning of each subsequent session.

Participants completed a cycle ergometer ramp test to exhaustion (Lode Excalibur, Groningen, Netherlands) to determine $\dot{V}O_{2max}$ and VT. The ergometer was set in hyperbolic mode and participants were informed that they could cycle at their preferred cadence. Participants cycled for 5 min at 60 W to familiarise themselves with the ergometer. They then dismounted, fitted a heart rate (HR) monitor (Polar Electro, Finland), and were attached to the online gas analyser (Cortex MetaMax 3B, Leipzig, Germany) via a two-way non-rebreathing facemask (7450 Series V2, Hans Rudolph, Kansas, USA). The analyser was calibrated according to manufacturer instructions prior to each use. Participants sat quietly for 5 min then remounted the ergometer and completed the warm-up and first two test stages. The facemask was then removed and participants sat for 5 min.

The test, adapted from Bergstrom et al. (2013), began at 60 W for 2 min, after which power output increased by 15 W·min^{-1} until volitional exhaustion or cadence dropped below 60 rev·min^{-1} for more than 10 s despite strong verbal encouragement. Participants' $\dot{V}O_{2max}$ was determined as the highest 30 s average, provided that at least two of the following criteria were met: a) ≥ 90% of age-predicted maximum HR; b) respiratory exchange ratio > 1.1; c) a plateau in $\dot{V}O_2$ (< 150 ml·min^{-1} increase during the last 60 s of the test) (Bergstrom et al., 2013). While valid $\dot{V}O_{2max}$ values can be gained from shorter protocols (Midgley et al., 2008), the primary outcome measure of the test was VT. Therefore, a published VT protocol was chosen.

The VT was determined using the V-slope method described by Beaver, Wasserman, and Whipp (1986), and defined as the $\dot{V}O_2$ corresponding to the intersection of two linear regression lines plotted below and above the visually determined breakpoint in the $\dot{V}CO_2$ versus $\dot{V}O_2$ relationship (Bergstrom et al., 2013). All resting and warm-up expired gas data was excluded from the analysis, and the data were checked to confirm that there was no hyperventilation at the start of the test. The VT determined from the V-slope method was confirmed by examining plots of the ventilatory equivalents for

O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$) against $\dot{V}O_2$ (Davis, Frank, Whipp, & Wasserman, 1979). A systematic increase in $\dot{V}_E/\dot{V}O_2$ without a corresponding increase in $\dot{V}_E/\dot{V}CO_2$, was the criterion for confirming VT. All VT determinations were undertaken by the same physiologist, and confirmed by a second physiologist. The power output/$\dot{V}O_2$ regression equation from the maximal test was used to determine the power output associated with $\dot{V}O_2$ at the VT (Bergstrom et al., 2013).

Exercise sessions

Participants completed three trials (Figure 1) in a randomised, Latin-square (3 x 3), crossover design. Within-participants, all trials were completed at the same time of day and separated by 3-7 days, with the same researcher and research assistant present. Participants completed a dietary record for 24 h before the first session and replicated this prior to subsequent sessions. They also refrained from strenuous physical or cognitive activity (such as long periods of intense concentration, which can influence perception of exercise difficulty; Marcora, Staiano, & Manning, 2009) and alcohol intake for ≥ 24 h before each session. Adherence to these procedures was confirmed at each visit. Trials began and ended with 2 min cycling at 60 W, followed by an additional 13 min of seated recovery post-exercise (total post-exercise time 15 min).

Moderate-Intensity Continuous Exercise

Participants cycled for 30 min at a power output equal to 85% of VT, which corresponds to a moderate intensity (Kilpatrick et al., 2007). This trial acted as a control, as measures of affect have previously shown minimal change during continuous exercise at this intensity (Ekkekakis et al., 2008; Kilpatrick et al., 2007).

High-Intensity Continuous Exercise

Participants cycled at a power output corresponding to 105% of VT, which corresponds to a hard intensity (Kilpatrick et al., 2007). Differences in total work may influence affective responses to exercise (Blanchard, Rodgers, Wilson, & Bell, 2004). Therefore, work done in HICE was the same as that done in MICE. This was achieved by reducing the exercise duration in HICE to account for the higher power output in this trial.

High-Intensity Interval Exercise

Participants completed 10 x 6 s all-out cycling efforts against 7.5% of BM, interspersed with 60 s recovery, on a mechanically braked cycle ergometer (Monark Ergomedic 814E, Vansbro, Sweden). The first 50 s of recovery was passive. From 50-59 s, participants cycled unloaded at 60 rev·min^{-1}. At 59 s, participants cycled maximally for 1 s unloaded, after which the resistance was added to the flywheel and the 6 s sprint began. This protocol has been shown to substantially improve aerobic capacity, physical function, and metabolic health in untrained adults (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014). A laboratory protocol was chosen to standardise the exercise sessions and provide a clearer causal relationship between low volume HIIE and affective responses, and a stronger justification for follow-up work using a more practical field-based protocol.

Total session duration, exercise duration, or work performed in HIIE was not matched to MICE and HICE, as one of the attractive characteristics of HIIE is its ability to elicit health and fitness improvements with notably less work and time commitment than continuous submaximal exercise (Babraj et al., 2009).

During MICE and HICE, the researcher and research assistant remained out of eyesight of the participants and did not communicate with them other than to record in-exercise measurements. This was not possible during HIIE due to the requirement to add and remove resistance to the flywheel, and to instruct the participant to stop and start each sprint. However, no encouragement was provided during HIIE.

* FIGURE 1 HERE *

Measurements

Heart rate was recorded throughout at 5 s intervals. The Borg CR-10 scale assessed RPE, as ratio scales provide more accurate insights into perceptual processes during exercise than the 6-20 RPE scale (Borg & Kaijser, 2006; Oliveira et al., 2013). Affective valence (pleasure/displeasure) was assessed using the FS, ranging from -5 (very bad) to +5 (very good). Perceived activation was measured using the FAS, ranging from 1 (low arousal) to 6 (high arousal). All scales were administered at rest prior to the warm-up (except RPE), in the last 30 s of the warm-up, every 20% of exercise time, and 1, 5, 10, and 15 min post-exercise (RPE at 1 min post-exercise only). In the HIIE trial, scales were taken immediately following sprints 2, 4, 6, 8, and 10 (still ~20% of exercise duration), due to the logistical problem of collecting this information during an all-out cycling effort. Laminated copies of each scale were held in front of the participant, who was asked to provide a number for each scale according to how they felt at that moment (Oliveira et al., 2013; Saanijoki et al., 2015).

Data from the FS and FAS were represented in the circumplex model, which describes a combined affective state with respect to activation and valence (Oliveira et al., 2013). This model was used as it includes positive and negative valence, high and low activation states, and is not domain-specific, making it appropriate for assessing affect before, during, and after exercise (Ekkekakis et al., 2008).

Statistical analyses

Analyses were performed using IBM SPSS Statistics 21 for Windows (IBM Corp., Chicago, IL). The Shapiro-Wilk test assessed the distribution of all data sets. Work related characteristics of exercise were compared using one-way repeated measures ANOVA and post-hoc pairwise comparisons with the Bonferroni correction. Affective valence and perceived activation during exercise were examined using a two-way (3 trials and 6 time points (warm-up, 20, 40, 60, 80, and 100% of exercise)) repeated measures ANOVA. The same variables post-exercise were examined using a two-way (3 trials and 5 time points (100% of exercise, 1, 5, 10, and 15 min post-exercise)) repeated measures ANOVA. Post hoc pairwise comparisons with the Bonferroni correction explored significant main effects. This analysis follows the same approach as Ekkekakis et al. (2008) in a related study. An alpha level of $P < 0.05$ was used in all tests except when the Bonferroni correction was applied. Cohen's *d* effect sizes (ES) for within-participants designs (Lakens, 2013) were calculated for pairwise comparisons and defined as trivial ($d < 0.2$), small ($d \geq 0.2, < 0.5$), medium ($\geq 0.5, < 0.8$), and large ($d \geq 0.8$) (Cohen, 1992).

RESULTS

Intensity manipulations

Table 1 presents mean performance data and physiological responses from the three trials. By design, MICE and HICE were equal in terms of total work performed and differed statistically in duration and intensity. The MICE and HIIE trials differed statistically across all variables with the exception of mean HR. The HICE and HIIE trials also differed statistically for all variables except RPE.

* TABLE 1 HERE *

During Exercise

Affective valence

There were no statistically significant effects of trial ($F_{1.2,13.6} = 1.02$, $P = 0.350$), time ($F_{1.6,17.8} = 3.57$, $P = 0.058$), or interaction ($F_{2.6,28.5} = 2.57$, $P = 0.081$) for affective valence during exercise (Figure 2A). However, differences in affective valence progressively increased during exercise between MICE and HICE (mean difference 0.0 ± 1.0, $d = 0.20$ at warm-up to 1.5 ± 2.3, $d = 0.66$ at 100% of exercise) and MICE and HIIE (mean difference 0.1 ± 1.1, $d = 0.16$ at warm-up to 0.9 ± 1.6, $d = 0.59$ at

100% of exercise). The difference in affective valence between HICE and HIIE was fairly stable over time (mean difference 0.1 ± 1.2, d = 0 at warm-up to 0.6 ± 3.2, d = 0.18 at 100% of exercise). Within-trials, the largest reduction in affective valence (warm-up to 100% of exercise) occurred in HICE (-1.75 ± 2.42 units, d = 0.72), followed by HIIE (-1.17 ± 1.99 units, d = 0.59) and MICE (-0.42 ± 1.38 units, d = 0.30).

Perceived activation

There were statistically significant main effects of trial ($F_{2,22}$ = 13.91, P < 0.001), time ($F_{1.6,18.3}$ = 40.12, P < 0.001), and trial x time interaction ($F_{4.1,45.6}$ = 4.14, P = 0.006) for perceived activation during exercise (Figure 2B). There were no statistical differences between conditions at baseline or warm-up. The MICE and HIIE trials differed statistically throughout exercise, with differences remaining large between 20% (P = 0.002, d = 1.37) and 100% (P = 0.002, d = 1.36) of exercise. The MICE and HICE trials differed statistically at 60% (P = 0.006, d = 1.16), 80% (P = 0.006, d = 1.17), and 100% (P = 0.021, d = 0.96) of exercise. The HICE and HIIE trials did not differ statistically at any time (largest difference at 20% of exercise, P = 0.075, d = 0.75).

* FIGURE 2 HERE *

Post-exercise

Affective valence

There were no statistically significant main effects of trial ($F_{1.1,12.5}$ = 3.09, *P* = 0.100) or trial x time interaction ($F_{2.4,26.9}$ = 1.17, *P* = 0.333) for affective valence post-exercise (Figure 2A). However, there was a main effect of time ($F_{1.3,14.5}$ = 11.11, *P* = 0.003). Affective valence was statistically greater 5 (*P* = 0.048, *d* = 0.81), 10 (*P* = 0.038, *d* = 0.61) and 15 min (*P* = 0.041, *d* = 0.67) post-exercise compared with 100% of exercise.

Perceived activation

There were statistically significant main effects of trial ($F_{2,22}$ = 10.68, *P* = 0.001), time ($F_{4,44}$ = 68.0, *P* < 0.001), and trial x time interaction ($F_{3.1,33.9}$ = 4.80, *P* = 0.006) for perceived activation post-exercise (Figure 2B). Perceived activation declined statistically more between 100% of exercise and 5 (*P* = 0.013, *d* = 0.86) and 15 min (*P* = 0.008, *d* = 0.93) post-exercise in HICE vs. MICE, and between 100% of exercise and 5 (*P* = 0.002, *d* = 1.20), 10 (*P* = 0.006, *d* = 0.97), and 15 min (*P* = 0.004, *d* = 1.05) post-exercise in HIIE vs. MICE. There were no statistical interactions between HICE and HIIE.

Circumplex model

The patterns of the circumplex model for each trial are in Figure 3. For MICE, low activation and positive affect (associated with a sense of calmness) was observed at all time points. In HICE, participants ranged from low activation and positive affect (calmness) prior to exercise and for the first 40% of exercise to high activation and positive affect (associated with a sense of energy) from 60-100% of exercise. Post-exercise, participants again experienced low activation and positive affect (calmness). In the HIIE trial, participants experienced low activation and positive affect (calmness) prior to exercise, high activation and positive affect (energy) throughout and immediately following exercise, and low activation and positive affect (calmness) for the remainder of the recovery. At no point during any of the trials did participants experience high activation and negative affect (associated with tension) or low activation and negative affect (associated with tiredness).

* FIGURE 3 HERE *

DISCUSSION

This study compared acute affective responses during and after MICE, HICE, and a low volume, time-efficient HIIE protocol in young, physically active, untrained males. Cardiovascular strain was similar between HICE and HIIE, and greater in these trials compared to MICE. During exercise, there were no statistically significant differences in affective responses between conditions or across time. However, differences in affective valence progressively increased during exercise in MICE compared to both HICE and HIIE, with moderate ES reported. The difference in affective valence between HICE and HIIE was fairly stable. Affective valence during exercise demonstrated the largest reduction in HICE, followed by HIIE, with the lowest reduction in MICE. Post-exercise, there were no statistically significant differences between conditions, however at 5 min post-exercise, affective valence statistically exceeded end-exercise values in all trials.

Differences in total work completed can influence affective responses to exercise, potentially masking any moderating influence of exercise intensity (Blanchard et al., 2004). The MICE and HICE trials involved the same amount of work, but differed statistically in duration and measures of intensity. Therefore, the experimental manipulation of the steady-state protocols based on intensity was successful. The HIIE session involved less total work and was shorter than both steady-state protocols, in line with the suggestion that HIIE is attractive due to its lower work and time commitment (Babraj et al., 2009). Mean power output was statistically greater in the work bouts of HIIE compared to MICE and HICE. Therefore, HIIE represented a notably different exercise challenge than MICE and HICE.

Although not statistically significant, the difference in affective valence between MICE and HICE, and MICE and HIIE, increased from trivial ES at the onset of exercise to medium ES at 100% of exercise. Affective valence during HICE and HIIE was consistently less positive than MICE, suggesting they are experienced as less pleasurable. The responses in MICE and HICE reinforce the finding that continuous exercise >VT generates less pleasant affective valence than continuous exercise <VT (Astorino et al., 2016; Ekkekakis et al., 2008).

In contrast, the difference in affective valence between HICE and HIIE remained small and stable with increasing duration. Therefore, the current study provides novel data showing that affective valence during a low volume HIIE protocol is similar to HICE.

Previous research has reported inconsistent findings on affective responses between HIIE and HICE, perhaps due to methodological issues and the use of different HIIE protocols (Jung et al., 2014; Oliveira et al., 2013; Saanijoki et al., 2015). From both a statistical significance and practical meaningfulness (ES) perspective, the current findings do not support the suggestion of (Jung et al., 2014) that HIIE may be less aversive than HICE. It is important to also note that the affective responses in both trials in the current study did not decrease to a negative level. Furthermore, in the current study the affective valence responses to HIIE were less negative compared to HICE than in the study of Oliveira et al. (2013), which supports the contention that different HIIE protocols can elicit different affective responses (Martinez et al., 2015). Our study provides further evidence that it may be feasible to manipulate HIIE parameters to induce positive (or less negative) affect (Jung et al., 2016), and that for these reasons, HIIE should not be considered inferior to HICE or MICE in its affective responses (Saanijoki et al., 2015).

The lack of a statistically significant between-trials effect for affective valence during exercise may be due to the larger inter-individual variability in affective valence during HICE and HIIE compared to MICE. Affective responses to HIIE are influenced by physical activity status and training experience (Frazao et al., 2016; Saanijoki et al., 2015), and potentially by individual differences in preference for and tolerance of high-intensity exercise (Ekkekakis, Hall, & Petruzzello, 2005a). Participants in the current study were physically active and not highly trained, which lent some homogeneity to the sample. Nevertheless, habitual physical activity levels were not strictly controlled, therefore it is possible that differences in this variable may have contributed to the greater variability in affective valence in HIIE and HICE.

However, the mean $\dot{V}O_{2max}$ and $\dot{V}O_2$ at percentages of VT data indicate that there was not a large variability in markers of aerobic fitness in the sample. The variability in affective valence during HIIE warrants further study, as identifying factors that can predict exercise preference may lead to more targeted exercise prescription (Ekkekakis et al., 2005a). It should also be considered that the absence of statistical significance for affective valence during exercise may be due to a Type II error related to statistical power. However, our analysis procedures combining inferential statistical results with measures of ES help to mitigate any potential influence of sub-optimal statistical power on data interpretation.

The circumplex model is a dimensional analysis of affect that incorporates affective valence and perceived activation to give a more complete view of affective responses (Ekkekakis et al., 2008). However, this analysis has had limited consideration in HIIE research, with the exception of Oliveira et al. (2013). The circumplex data for MICE and HICE in the current study are similar to that of Ekkekakis et al. (2008) for running < and >VT. The profile for HIIE did not include negative feeling states at any time, and was similar to HICE. This contrasts with Oliveira et al. (2013), where participants reported negative feeling responses during HIIE with much longer work periods than the current study, but not during their HICE trial. These data further support the suggestion that manipulation of HIIE variables can alter the affective responses to HIIE (Jung et al., 2016; Martinez et al., 2015). These affective alterations may be due, at least partly, to shifts in the dependence on anaerobic metabolism (Oliveira et al., 2013). If low volume HIIE is not perceived more negatively than HICE, and confers meaningful health and fitness improvements (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014), it may represent an attractive alternative form of exercise due to its reduced time commitment. The potential attraction of low volume, time-efficient HIIE is lent further credence by data showing that affective responses to HIIE improve when the exercise is repeated (Saanijoki et al., 2015).

In addition to affect during exercise, this study also focused on post-exercise affect as this may have an influence on future behaviour (Kahneman et al., 1993), and has had limited consideration in HIIE research. Our data showed that post-HIIE affective valence improved at the same rate as HICE and MICE. Post-exercise circumplex values for HIIE were also similar to MICE and HICE, reinforcing that the low volume HIIE protocol in the current study did not lead to negative post-exercise affect. The smaller affective rebound at 5 min post-HIIE in our study compared to that of Oliveira et al. (2013) is probably due to the more positive affect reported during HIIE in the current study, meaning the participants had a smaller affective "deficit" from which to rebound. Although further research is required to understand the relationship between post-exercise affect and future behaviour (Hargreaves & Stych, 2013; Jung et al., 2016; Rhodes & Kates, 2015), the findings of the current study suggest that because the post-exercise affective response to HIIE is similar to HICE and MICE then it could have a similar relationship to future behaviour. This lends further support to the suggestion that low volume, time efficient, efficacious HIIE may represent an attractive alternative form of exercise, at least in physically active young men.

This study recruited relatively young, physically active participants. While this is not a highly trained or athletic sample, caution should be used when attempting to generalise our findings to an inactive and/or older population. However, HIIE protocols very similar to ours have proved efficacious and well tolerated in inactive older people (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014; Allison et al., 2016). Furthermore, contemporary debate advocates the use of fewer and shorter work bouts in HIIE protocols for the general population, including older and inactive people (Vollaard & Metcalfe, 2017). Our low-volume HIIE protocol meets this suggestion. These points, coupled with the justification for our HIIE protocol described elsewhere in this paper, suggest that the affective responses to the low-volume HIIE protocol reported in this study may not be notably different in an older or less active population. Of course, this suggestion should be empirically tested.

We have presented novel data to show that low volume HIIE with higher relative intensity does not induce more negative affective responses during or after exercise than MICE or HICE. Based on the documented improvement in affect with repeated exposure to HIIE, low volume, time efficient HIIE may be an attractive alternative exercise prescription for improving health and fitness.

Geolocation Information

The research was conducted in Edinburgh, Scotland. Participants were recruited from the local area. Specific nationalities were not a focus of the research and were not recorded.

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Disclosure of interest

The authors report no conflicts of interest.

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FIGURE CAPTIONS

Figure 1. Schematic of the experimental protocol. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise.

Figure 2. Feeling state (A) and felt arousal (B) at baseline, during, and after exercise for all trials. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise. * Significantly greater than 100% of exercise in all trials; ** Significantly lower in MICE vs. HIIE; *** Significantly lower in MICE vs. HICE; † Significantly greater reduction in HICE vs MICE; ‡ Significantly greater reduction in HIIE vs. MICE.

Figure 3: Affective circumplex model applied to the MICE, HICE, and HIIE sessions. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise.

Manuscript - with author details

Comparison of affective responses during and after low volume high-intensity interval exercise, continuous moderate- and continuous high-intensity exercise in active, untrained, healthy males

Running title: affective responses to reduced volume high-intensity interval exercise

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Keywords: interval training; intermittent exercise; enjoyment; adherence

Abstract

This study compared affective responses to low volume high-intensity interval exercise (HIIE), moderate-intensity continuous exercise (MICE) and high-intensity continuous exercise (HICE). Twelve untrained males ($\dot{V}O_{2max}$ 48.2 ± 6.7 ml·kg^{-1}·min^{-1}) completed MICE (30 min cycle at 85% of ventilatory threshold (VT)), HICE (cycle at 105% of VT matched with MICE for total work), and HIIE (10 x 6 s cycle sprints with 60 s recovery). Affective valence and perceived activation were measured before exercise, post warm-up, every 20% of exercise time, and 1, 5, 10, and 15 min post-exercise. Affective valence during exercise declined by 1.75 ± 2.42, 1.17 ± 1.99, and 0.42 ± 1.38 units in HICE, HIIE, and MICE, respectively, but was not statistically influenced by trial (P = 0.35), time (P = 0.06), or interaction effect (P = 0.08). Affective valence during HICE and HIIE was consistently less positive than MICE. Affective valence post-exercise was not statistically influenced by trial (P = 0.10) and at 5 min post-exercise exceeded end-exercise values (P = 0.048). Circumplex profiles showed no negative affect in any trial. Affective responses to low volume HIIE are similar to HICE but remain positive and rebound rapidly, suggesting it may be a potential alternative exercise prescription.

Introduction

More than 30% of the worldwide population are insufficiently physically active for health (Hallal, 2012). Lack of time is a commonly cited barrier to completing sufficient physical activity (Aaltonen et al., 2012). Low volume high-intensity interval exercise (HIIE) is brief, repeated bursts of intense or all-out exercise separated by rest or low-intensity exercise, with total intense exercise time ≤10 min per session and total session time ≤30 min (Gillen & Gibala, 2014). Low volume HIIE can considerably improve aerobic fitness, body composition, and cardiometabolic health in a variety of populations (Babraj et al., 2009; Jakeman, Adamson, & Babraj, 2012; Tjonna et al., 2009). Therefore, low volume HIIE is a time efficient strategy for improving health and fitness (Gillen & Gibala, 2014) that may appeal to individuals with limited time to be active.

Many HIIE protocols are extremely challenging due to their high-intensity nature (Gillen & Gibala, 2014), which has led to debate around the public health value of HIIE. Several researchers have argued that individuals are unlikely to engage with, or adhere to HIIE (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014), partly because they will find it unpleasant and therefore be unlikely to repeat the experience (Rhodes & Kates, 2015). According to the dual-mode theory of affective responses to exercise (Ekkekakis, 2003), intensity is a key mediator of the affective response. Exercise above the ventilatory threshold (VT) typically leads to more unpleasant affective responses than exercise at and below VT (Astorino et al., 2016; Ekkekakis, Hall, & Petruzzello, 2008; Kilpatrick, Kraemer, Bartholomew, Acevedo, & Jarreau, 2007). However, the dual-mode theory applies to continuous exercise, and the intermittent nature of HIIE with regular recovery opportunities may allow participants to experience more positive affective responses (Jung, Bourne, & Little, 2014; Jung, Little, & Batterham, 2016).

However, an emerging body of literature suggests that HIIE generates less positive affect compared to continuous submaximal exercise (Jung et al., 2014; Oliveira, Slama, Deslandes, Furtado, & Santos, 2013; Saanijoki et al., 2015). Whilst these studies suggest that HIIE is experienced less positively compared with more moderate exercise, findings may be clouded by methodological issues. Some studies (Jung et al., 2014; Saanijoki et al., 2015) standardised continuous intensity exercise to a percentage of peak power (W_{peak}). The relative demands and tolerable duration of exercise are not adequately characterised using this approach, and instead exercise intensity domains should take account of individualised intensity thresholds, such as the VT (Mann, Lamberts, & Lambert, 2013). Additionally, the HIIE protocol used by Jung et al. (2014) was the same duration as their continuous high-intensity protocol, and the protocols of Oliveira et al. (2013), Saanijoki et al. (2015), and Decker and Ekkekakis (2016) lasted ~17-23 min, excluding warm-up and cool-down. This negates the practical attraction of reduced exercise duration with HIIE. Furthermore, the protocols adopted by Saanijoki et al. (2015) and Oliveira et al. (2013) were particularly arduous, making unclear the transferability of the findings to HIIE protocols that may be more palatable.

There has been a concerted effort to develop low volume HIIE protocols that are efficacious, time efficient, and more palatable (Gillen & Gibala, 2014). Protocols involving 20-60 s of total work within a 7-10 min exercise session can substantially improve aerobic fitness and cardiometabolic health (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, & Babraj, 2014; Allison, Martin, MacInnis, Gurd, & Gibala, 2016). However, affective responses to these protocols are not well understood. It is plausible that affective responses may be less negative than in previously reported HIIE data, due to shorter and less frequent work bouts (Jung et al., 2014; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015), and larger work-to-rest ratios implying less reliance on anaerobic metabolism relative to session duration. Recent work on the affective responses to HIIE specifically called for research to investigate affective responses to reduced volume HIIE protocols (Decker & Ekkekakis, 2016). While some research has compared affective responses to different volumes of HIIE (Martinez et al., 2015; Wood et al., 2016), a low volume HIIE protocol (i.e. 20-60 s total work) was not used.

How people feel *after* HIIE may also be of importance, as affect at the end of the task may influence future behaviour (Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993). Although in their recent review, Rhodes and Kates (2015) concluded the evidence did not support a relationship between post-exercise affect and future physical activity behaviour, this was based on only nine studies of varying quality with mixed findings, highlighting the need for further research. Further, Rhodes and Kates (2015) acknowledged the counter theoretical argument that the end of the task may be the most powerful affective stimulus (Hargreaves & Stych, 2013; Kahneman et al.). This perspective is important to investigate further because according to dual-mode theory there is likely to be a ‘rebound’ from affective negativity to positivity following exercise, regardless of intensity (Ekkekakis, 2003), and within 1 min following severe-intensity exercise (Ekkekakis, Hall, & Petruzzello, 2005b). Therefore, it is possible that affective responses post-HIIE are similar to responses following exercise at a lower intensity. Limited research has focused on affect post-HIIE with recent studies either not assessing post-exercise affect (Frazao et al., 2016; Saanijoki et al., 2015) or assessing affect at a later point (Jung et al., 2014; Oliveira et al., 2013) and potentially missing the window to document and compare the rebound effect.

The development of effective, time efficient, and palatable HIIE protocols would be an important step forward for the implementation of HIIE into public health strategies. Efficacy and time efficiency have been established; affective responses during and after these reduced volume protocols have not been well examined. The aim of this study was to compare affective responses during and after low volume HIIE, moderate-intensity continuous exercise (MICE) and high-intensity continuous exercise (HICE). We hypothesised that cardiovascular strain would be similar in the HICE and HIIE trials, and greater than the MICE trial; affective valence would decrease more during HIIE than MICE, but less than during HICE; and post-exercise affective valence would rebound within the same time-frame in all trials.

METHODS

Participants

Twelve healthy, physically active males participated (mean ± SD age 25 ± 7 years (range 19-35 years), height 177 ± 7 cm, body mass (BM) 76.5 ± 12.2 kg, maximal oxygen uptake ($\dot{V}O_{2max}$) 48.2 ± 6.7 ml·kg^{-1}·min^{-1}, W_{peak} 297 ± 36 W). Participants were generally physically active (≥ 150 min habitual physical activity per week

(National Health Service, 2013); physically active for ≥ 30 min on 5 ± 1.6 days per week (range 2-7)), untrained (below the age-gender 90th percentile for $\dot{V}O_{2max}$ (American College of Sports Medicine, 2005)), not participating in/training for a competition or event, and unfamiliar with HIIE. The sample consisted of five University staff members and seven undergraduate students (one computer science, one primary education, and five sport science students). The study was explained to participants, and written informed consent was gained. All work was conducted with the formal approval of the University of Edinburgh, Moray House School of Education Ethics Committee.

Baseline trial

All sessions took place in the same climate controlled laboratory (temperature 20-21°C, relative humidity 50-55%). In visit one, anthropometric data were collected (BM: model 708; Seca, Hamburg, Germany; standing height: model 245; Seca, Hamburg, Germany), and standardised explanations of the Borg CR-10 Rating of Perceived Exertion (RPE) scale, Feeling Scale (FS, (Hardy & Rejeski, 1989)), and Felt Arousal scale (FAS, (Svebak & Murgatroyd, 1985)) were provided according to the instructions in the original publications. These explanations were briefly reviewed at the beginning of each subsequent session.

Participants completed a cycle ergometer ramp test to exhaustion (Lode Excalibur, Groningen, Netherlands) to determine $\dot{V}O_{2max}$ and VT. The ergometer was set in hyperbolic mode and participants were informed that they could cycle at their preferred cadence. Participants cycled for 5 min at 60 W to familiarise themselves with the ergometer. They then dismounted, fitted a heart rate (HR) monitor (Polar Electro, Finland), and were attached to the online gas analyser (Cortex MetaMax 3B, Leipzig, Germany) via a two-way non-rebreathing facemask (7450 Series V2, Hans Rudolph, Kansas, USA). The analyser was calibrated according to manufacturer instructions prior to each use. Participants sat quietly for 5 min then remounted the ergometer and completed the warm-up and first two test stages. The facemask was then removed and participants sat for 5 min.

The test, adapted from Bergstrom et al. (2013), began at 60 W for 2 min, after which power output increased by 15 W·min^{-1} until volitional exhaustion or cadence dropped below 60 rev·min^{-1} for more than 10 s despite strong verbal encouragement. Participants' $\dot{V}O_{2max}$ was determined as the highest 30 s average, provided that at least two of the following criteria were met: a) ≥ 90% of age-predicted maximum HR; b) respiratory exchange ratio > 1.1; c) a plateau in $\dot{V}O_2$ (< 150 ml·min^{-1} increase during the last 60 s of the test) (Bergstrom et al., 2013). While valid $\dot{V}O_{2max}$ values can be gained from shorter protocols (Midgley et al., 2008), the primary outcome measure of the test was VT. Therefore, a published VT protocol was chosen.

The VT was determined using the V-slope method described by Beaver, Wasserman, and Whipp (1986), and defined as the $\dot{V}O_2$ corresponding to the intersection of two linear regression lines plotted below and above the visually determined breakpoint in the $\dot{V}CO_2$ versus $\dot{V}O_2$ relationship (Bergstrom et al., 2013). All resting and warm-up expired gas data was excluded from the analysis, and the data were checked to confirm that there was no hyperventilation at the start of the test. The VT determined from the V-slope method was confirmed by examining plots of the ventilatory equivalents for

O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$) against $\dot{V}O_2$ (Davis, Frank, Whipp, & Wasserman, 1979). A systematic increase in $\dot{V}_E/\dot{V}O_2$ without a corresponding increase in $\dot{V}_E/\dot{V}CO_2$, was the criterion for confirming VT. All VT determinations were undertaken by the same physiologist, and confirmed by a second physiologist. The power output/$\dot{V}O_2$ regression equation from the maximal test was used to determine the power output associated with $\dot{V}O_2$ at the VT (Bergstrom et al., 2013).

Exercise sessions

Participants completed three trials (Figure 1) in a randomised, Latin-square (3 x 3), crossover design. Within-participants, all trials were completed at the same time of day and separated by 3-7 days, with the same researcher and research assistant present. Participants completed a dietary record for 24 h before the first session and replicated this prior to subsequent sessions. They also refrained from strenuous physical or cognitive activity (such as long periods of intense concentration, which can influence perception of exercise difficulty; Marcora, Staiano, & Manning, 2009) and alcohol intake for ≥ 24 h before each session. Adherence to these procedures was confirmed at each visit. Trials began and ended with 2 min cycling at 60 W, followed by an additional 13 min of seated recovery post-exercise (total post-exercise time 15 min).

Moderate-Intensity Continuous Exercise

Participants cycled for 30 min at a power output equal to 85% of VT, which corresponds to a moderate intensity (Kilpatrick et al., 2007). This trial acted as a control, as measures of affect have previously shown minimal change during continuous exercise at this intensity (Ekkekakis et al., 2008; Kilpatrick et al., 2007).

High-Intensity Continuous Exercise

Participants cycled at a power output corresponding to 105% of VT, which corresponds to a hard intensity (Kilpatrick et al., 2007). Differences in total work may influence affective responses to exercise (Blanchard, Rodgers, Wilson, & Bell, 2004). Therefore, work done in HICE was the same as that done in MICE. This was achieved by reducing the exercise duration in HICE to account for the higher power output in this trial.

High-Intensity Interval Exercise

Participants completed 10 x 6 s all-out cycling efforts against 7.5% of BM, interspersed with 60 s recovery, on a mechanically braked cycle ergometer (Monark Ergomedic 814E, Vansbro, Sweden). The first 50 s of recovery was passive. From 50-59 s, participants cycled unloaded at 60 rev·min^{-1}. At 59 s, participants cycled maximally for 1 s unloaded, after which the resistance was added to the flywheel and the 6 s sprint began. This protocol has been shown to substantially improve aerobic capacity, physical function, and metabolic health in untrained adults (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014). A laboratory protocol was chosen to standardise the exercise sessions and provide a clearer causal relationship between low volume HIIE and affective responses, and a stronger justification for follow-up work using a more practical field-based protocol.

Total session duration, exercise duration, or work performed in HIIE was not matched to MICE and HICE, as one of the attractive characteristics of HIIE is its ability to elicit health and fitness improvements with notably less work and time commitment than continuous submaximal exercise (Babraj et al., 2009).

During MICE and HICE, the researcher and research assistant remained out of eyesight of the participants and did not communicate with them other than to record in-exercise measurements. This was not possible during HIIE due to the requirement to add and remove resistance to the flywheel, and to instruct the participant to stop and start each sprint. However, no encouragement was provided during HIIE.

* FIGURE 1 HERE *

Measurements

Heart rate was recorded throughout at 5 s intervals. The Borg CR-10 scale assessed RPE, as ratio scales provide more accurate insights into perceptual processes during exercise than the 6-20 RPE scale (Borg & Kaijser, 2006; Oliveira et al., 2013). Affective valence (pleasure/displeasure) was assessed using the FS, ranging from -5 (very bad) to +5 (very good). Perceived activation was measured using the FAS, ranging from 1 (low arousal) to 6 (high arousal). All scales were administered at rest prior to the warm-up (except RPE), in the last 30 s of the warm-up, every 20% of exercise time, and 1, 5, 10, and 15 min post-exercise (RPE at 1 min post-exercise only). In the HIIE trial, scales were taken immediately following sprints 2, 4, 6, 8, and 10 (still ~20% of exercise duration), due to the logistical problem of collecting this information during an all-out cycling effort. Laminated copies of each scale were held in front of the participant, who was asked to provide a number for each scale according to how they felt at that moment (Oliveira et al., 2013; Saanijoki et al., 2015).

Data from the FS and FAS were represented in the circumplex model, which describes a combined affective state with respect to activation and valence (Oliveira et al., 2013). This model was used as it includes positive and negative valence, high and low activation states, and is not domain-specific, making it appropriate for assessing affect before, during, and after exercise (Ekkekakis et al., 2008).

Statistical analyses

Analyses were performed using IBM SPSS Statistics 21 for Windows (IBM Corp., Chicago, IL). The Shapiro-Wilk test assessed the distribution of all data sets. Work related characteristics of exercise were compared using one-way repeated measures ANOVA and post-hoc pairwise comparisons with the Bonferroni correction. Affective valence and perceived activation during exercise were examined using a two-way (3 trials and 6 time points (warm-up, 20, 40, 60, 80, and 100% of exercise)) repeated measures ANOVA. The same variables post-exercise were examined using a two-way (3 trials and 5 time points (100% of exercise, 1, 5, 10, and 15 min post-exercise)) repeated measures ANOVA. Post hoc pairwise comparisons with the Bonferroni correction explored significant main effects. This analysis follows the same approach as Ekkekakis et al. (2008) in a related study. An alpha level of $P <$ 0.05 was used in all tests except when the Bonferroni correction was applied. Cohen's *d* effect sizes (ES) for within-participants designs (Lakens, 2013) were calculated for pairwise comparisons and defined as trivial ($d < 0.2$), small ($d \geq 0.2, < 0.5$), medium ($\geq 0.5, < 0.8$), and large ($d \geq 0.8$) (Cohen, 1992).

RESULTS

Intensity manipulations

Table 1 presents mean performance data and physiological responses from the three trials. By design, MICE and HICE were equal in terms of total work performed and differed statistically in duration and intensity. The MICE and HIIE trials differed statistically across all variables with the exception of mean HR. The HICE and HIIE trials also differed statistically for all variables except RPE.

* TABLE 1 HERE *

During Exercise

Affective valence

There were no statistically significant effects of trial ($F_{1.2,13.6} = 1.02$, $P = 0.350$), time ($F_{1.6,17.8} = 3.57$, $P = 0.058$), or interaction ($F_{2.6,28.5} = 2.57$, $P = 0.081$) for affective valence during exercise (Figure 2A). However, differences in affective valence progressively increased during exercise between MICE and HICE (mean difference 0.0 ± 1.0, $d = 0.20$ at warm-up to 1.5 ± 2.3, $d = 0.66$ at 100% of exercise) and MICE and HIIE (mean difference 0.1 ± 1.1, $d = 0.16$ at warm-up to 0.9 ± 1.6, $d = 0.59$ at

100% of exercise). The difference in affective valence between HICE and HIIE was fairly stable over time (mean difference 0.1 ± 1.2, d = 0 at warm-up to 0.6 ± 3.2, d = 0.18 at 100% of exercise). Within-trials, the largest reduction in affective valence (warm-up to 100% of exercise) occurred in HICE (-1.75 ± 2.42 units, d = 0.72), followed by HIIE (-1.17 ± 1.99 units, d = 0.59) and MICE (-0.42 ± 1.38 units, d = 0.30).

Perceived activation

There were statistically significant main effects of trial ($F_{2,22}$ = 13.91, $P < 0.001$), time ($F_{1.6,18.3}$ = 40.12, $P < 0.001$), and trial x time interaction ($F_{4.1,45.6}$ = 4.14, P = 0.006) for perceived activation during exercise (Figure 2B). There were no statistical differences between conditions at baseline or warm-up. The MICE and HIIE trials differed statistically throughout exercise, with differences remaining large between 20% (P = 0.002, d = 1.37) and 100% (P = 0.002, d = 1.36) of exercise. The MICE and HICE trials differed statistically at 60% (P = 0.006, d = 1.16), 80% (P = 0.006, d = 1.17), and 100% (P = 0.021, d = 0.96) of exercise. The HICE and HIIE trials did not differ statistically at any time (largest difference at 20% of exercise, P = 0.075, d = 0.75).

* FIGURE 2 HERE *

Post-exercise

Affective valence

There were no statistically significant main effects of trial ($F_{1.1,12.5} = 3.09$, $P = 0.100$) or trial x time interaction ($F_{2.4,26.9} = 1.17$, $P = 0.333$) for affective valence post-exercise (Figure 2A). However, there was a main effect of time ($F_{1.3,14.5} = 11.11$, $P = 0.003$). Affective valence was statistically greater 5 ($P = 0.048$, $d = 0.81$), 10 ($P = 0.038$, $d = 0.61$) and 15 min ($P = 0.041$, $d = 0.67$) post-exercise compared with 100% of exercise.

Perceived activation

There were statistically significant main effects of trial ($F_{2,22} = 10.68$, $P = 0.001$), time ($F_{4,44} = 68.0$, $P < 0.001$), and trial x time interaction ($F_{3.1,33.9} = 4.80$, $P = 0.006$) for perceived activation post-exercise (Figure 2B). Perceived activation declined statistically more between 100% of exercise and 5 ($P = 0.013$, $d = 0.86$) and 15 min ($P = 0.008$, $d = 0.93$) post-exercise in HICE vs. MICE, and between 100% of exercise and 5 ($P = 0.002$, $d = 1.20$), 10 ($P = 0.006$, $d = 0.97$), and 15 min ($P = 0.004$, $d = 1.05$) post-exercise in HIIE vs. MICE. There were no statistical interactions between HICE and HIIE.

Circumplex model

The patterns of the circumplex model for each trial are in Figure 3. For MICE, low activation and positive affect (associated with a sense of calmness) was observed at all time points. In HICE, participants ranged from low activation and positive affect (calmness) prior to exercise and for the first 40% of exercise to high activation and positive affect (associated with a sense of energy) from 60-100% of exercise. Post-exercise, participants again experienced low activation and positive affect (calmness). In the HIIE trial, participants experienced low activation and positive affect (calmness) prior to exercise, high activation and positive affect (energy) throughout and immediately following exercise, and low activation and positive affect (calmness) for the remainder of the recovery. At no point during any of the trials did participants experience high activation and negative affect (associated with tension) or low activation and negative affect (associated with tiredness).

* FIGURE 3 HERE *

DISCUSSION

This study compared acute affective responses during and after MICE, HICE, and a low volume, time-efficient HIIE protocol in young, physically active, untrained males. Cardiovascular strain was similar between HICE and HIIE, and greater in these trials compared to MICE. During exercise, there were no statistically significant differences in affective responses between conditions or across time. However, differences in affective valence progressively increased during exercise in MICE compared to both HICE and HIIE, with moderate ES reported. The difference in affective valence between HICE and HIIE was fairly stable. Affective valence during exercise demonstrated the largest reduction in HICE, followed by HIIE, with the lowest reduction in MICE. Post-exercise, there were no statistically significant differences between conditions, however at 5 min post-exercise, affective valence statistically exceeded end-exercise values in all trials.

Differences in total work completed can influence affective responses to exercise, potentially masking any moderating influence of exercise intensity (Blanchard et al., 2004). The MICE and HICE trials involved the same amount of work, but differed statistically in duration and measures of intensity. Therefore, the experimental manipulation of the steady-state protocols based on intensity was successful. The HIIE session involved less total work and was shorter than both steady-state protocols, in line with the suggestion that HIIE is attractive due to its lower work and time commitment (Babraj et al., 2009). Mean power output was statistically greater in the work bouts of HIIE compared to MICE and HICE. Therefore, HIIE represented a notably different exercise challenge than MICE and HICE.

Although not statistically significant, the difference in affective valence between MICE and HICE, and MICE and HIIE, increased from trivial ES at the onset of exercise to medium ES at 100% of exercise. Affective valence during HICE and HIIE was consistently less positive than MICE, suggesting they are experienced as less pleasurable. The responses in MICE and HICE reinforce the finding that continuous exercise >VT generates less pleasant affective valence than continuous exercise <VT (Astorino et al., 2016; Ekkekakis et al., 2008).

In contrast, the difference in affective valence between HICE and HIIE remained small and stable with increasing duration. Therefore, the current study provides novel data showing that affective valence during a low volume HIIE protocol is similar to HICE.

Previous research has reported inconsistent findings on affective responses between HIIE and HICE, perhaps due to methodological issues and the use of different HIIE protocols (Jung et al., 2014; Oliveira et al., 2013; Saanijoki et al., 2015). From both a statistical significance and practical meaningfulness (ES) perspective, the current findings do not support the suggestion of (Jung et al., 2014) that HIIE may be less aversive than HICE. It is important to also note that the affective responses in both trials in the current study did not decrease to a negative level. Furthermore, in the current study the affective valence responses to HIIE were less negative compared to HICE than in the study of Oliveira et al. (2013), which supports the contention that different HIIE protocols can elicit different affective responses (Martinez et al., 2015). Our study provides further evidence that it may be feasible to manipulate HIIE parameters to induce positive (or less negative) affect (Jung et al., 2016), and that for these reasons, HIIE should not be considered inferior to HICE or MICE in its affective responses (Saanijoki et al., 2015).

The lack of a statistically significant between-trials effect for affective valence during exercise may be due to the larger inter-individual variability in affective valence during HICE and HIIE compared to MICE. Affective responses to HIIE are influenced by physical activity status and training experience (Frazao et al., 2016; Saanijoki et al., 2015), and potentially by individual differences in preference for and tolerance of high-intensity exercise (Ekkekakis, Hall, & Petruzzello, 2005a). Participants in the current study were physically active and not highly trained, which lent some homogeneity to the sample. Nevertheless, habitual physical activity levels were not strictly controlled, therefore it is possible that differences in this variable may have contributed to the greater variability in affective valence in HIIE and HICE.

However, the mean $\dot{V}O_{2max}$ and $\dot{V}O_2$ at percentages of VT data indicate that there was not a large variability in markers of aerobic fitness in the sample. The variability in affective valence during HIIE warrants further study, as identifying factors that can predict exercise preference may lead to more targeted exercise prescription (Ekkekakis et al., 2005a). It should also be considered that the absence of statistical significance for affective valence during exercise may be due to a Type II error related to statistical power. However, our analysis procedures combining inferential statistical results with measures of ES help to mitigate any potential influence of sub-optimal statistical power on data interpretation.

The circumplex model is a dimensional analysis of affect that incorporates affective valence and perceived activation to give a more complete view of affective responses (Ekkekakis et al., 2008). However, this analysis has had limited consideration in HIIE research, with the exception of Oliveira et al. (2013). The circumplex data for MICE and HICE in the current study are similar to that of Ekkekakis et al. (2008) for running < and >VT. The profile for HIIE did not include negative feeling states at any time, and was similar to HICE. This contrasts with Oliveira et al. (2013), where participants reported negative feeling responses during HIIE with much longer work periods than the current study, but not during their HICE trial. These data further support the suggestion that manipulation of HIIE variables can alter the affective responses to HIIE (Jung et al., 2016; Martinez et al., 2015). These affective alterations may be due, at least partly, to shifts in the dependence on anaerobic metabolism (Oliveira et al., 2013). If low volume HIIE is not perceived more negatively than HICE, and confers meaningful health and fitness improvements (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014), it may represent an attractive alternative form of exercise due to its reduced time commitment. The potential attraction of low volume, time-efficient HIIE is lent further credence by data showing that affective responses to HIIE improve when the exercise is repeated (Saanijoki et al., 2015).

In addition to affect during exercise, this study also focused on post-exercise affect as this may have an influence on future behaviour (Kahneman et al., 1993), and has had limited consideration in HIIE research. Our data showed that post-HIIE affective valence improved at the same rate as HICE and MICE. Post-exercise circumplex values for HIIE were also similar to MICE and HICE, reinforcing that the low volume HIIE protocol in the current study did not lead to negative post-exercise affect. The smaller affective rebound at 5 min post-HIIE in our study compared to that of Oliveira et al. (2013) is probably due to the more positive affect reported during HIIE in the current study, meaning the participants had a smaller affective "deficit" from which to rebound. Although further research is required to understand the relationship between post-exercise affect and future behaviour (Hargreaves & Stych, 2013; Jung et al., 2016; Rhodes & Kates, 2015), the findings of the current study suggest that because the post-exercise affective response to HIIE is similar to HICE and MICE then it could have a similar relationship to future behaviour. This lends further support to the suggestion that low volume, time efficient, efficacious HIIE may represent an attractive alternative form of exercise, at least in physically active young men.

This study recruited relatively young, physically active participants. While this is not a highly trained or athletic sample, caution should be used when attempting to generalise our findings to an inactive and/or older population. However, HIIE protocols very similar to ours have proved efficacious and well tolerated in inactive older people (Adamson, Lorimer, Cobley, & Babraj, 2014; Adamson, Lorimer, Cobley, Lloyd, et al., 2014; Allison et al., 2016). Furthermore, contemporary debate advocates the use of fewer and shorter work bouts in HIIE protocols for the general population, including older and inactive people (Vollaard & Metcalfe, 2017). Our low-volume HIIE protocol meets this suggestion. These points, coupled with the justification for our HIIE protocol described elsewhere in this paper, suggest that the affective responses to the low-volume HIIE protocol reported in this study may not be notably different in an older or less active population. Of course, this suggestion should be empirically tested.

We have presented novel data to show that low volume HIIE with higher relative intensity does not induce more negative affective responses during or after exercise than MICE or HICE. Based on the documented improvement in affect with repeated exposure to HIIE, low volume, time efficient HIIE may be an attractive alternative exercise prescription for improving health and fitness.

Geolocation Information

The research was conducted in Edinburgh, Scotland. Participants were recruited from the local area. Specific nationalities were not a focus of the research and were not recorded.

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Disclosure of interest

The authors report no conflicts of interest.

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FIGURE CAPTIONS

Figure 1. Schematic of the experimental protocol. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise.

Figure 2. Feeling state (A) and felt arousal (B) at baseline, during, and after exercise for all trials. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise. * Significantly greater than 100% of exercise in all trials; ** Significantly lower in MICE vs. HIIE; *** Significantly lower in MICE vs. HICE; † Significantly greater reduction in HICE vs MICE; ‡ Significantly greater reduction in HIIE vs. MICE.

Figure 3: Affective circumplex model applied to the MICE, HICE, and HIIE sessions. MICE = moderate-intensity continuous exercise; HICE = high-intensity continuous exercise; HIIE = high-intensity interval exercise.

Table 1

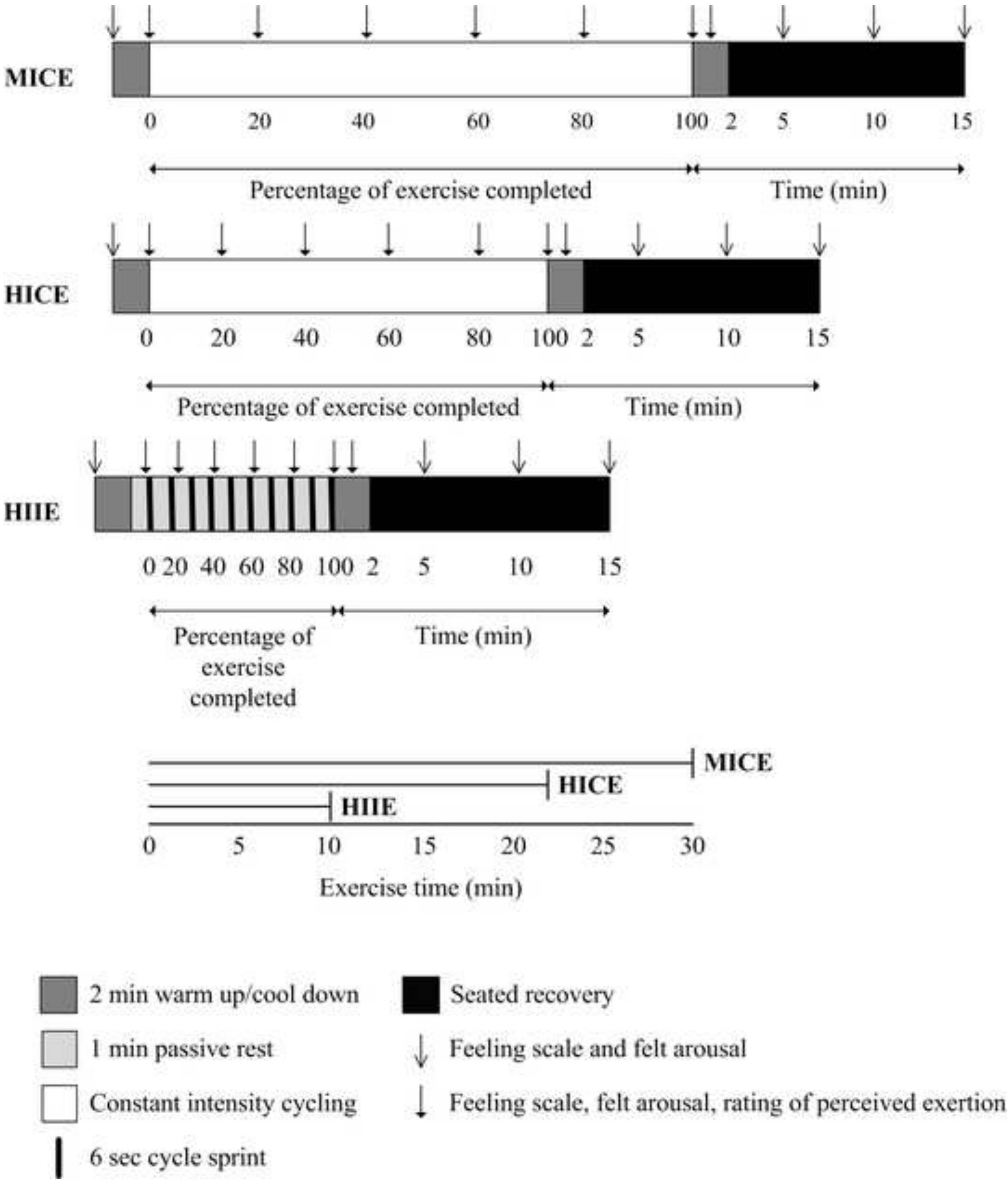
TABLE 1. Comparison of the three exercise trials.

	MICE	HICE	HIIE	MICE vs. HICE	MICE vs. HIIE	HICE vs. HIIE
Duration (min)	30.0 ± 0.0	22.1 ± 1.2	10.0 ± 0.0	*P* < 0.001 *d* = 6.42	*P* < 0.001*	*P* < 0.001 *d* = 9.79
Power (W)	130.3 ± 23.0	176.1 ± 23.3	774.3 ± 118.3	*P* < 0.001 *d* = 11.18	*P* < 0.001 *d* = 2.73	*P* < 0.001 *d* = 2.68
Peak Power (W)	-	-	809.6 ± 127.1	-	-	-
Work (kJ)	234.6 ± 41.3	234.6 ± 41.3	46.5 ± 7.1	*P* = 1.0 *d* = 0	*P* < 0.001 *d* = 2.61	*P* < 0.001 *d* = 2.61
VO_{2max} (%)	55.1 ± 4.5	68.3 ± 5.5	-	*P* < 0.001 *d* = 10.43	-	-
Heart rate ($b.min^{-1}$)	137 ± 15	159 ± 12	147 ± 12	*P* < 0.001 *d* = 1.65	*P* = 0.14 *d* = 0.65	*P* = 0.008 *d* = 1.11
Peak HR	146 ± 14	167 ± 13	158 ± 10	*P* = 0.001 *d* = 1.58	*P* = 0.049 *d* = 0.82	*P* = 0.032 *d* = 0.89
RPE	3.2 ± 0.9	5.4 ± 1.2	6.0 ± 1.6	*P* < 0.001	*P* < 0.001	*P* = 0.55

	d = 2.33	*d* = 2.26	*d* = 0.41

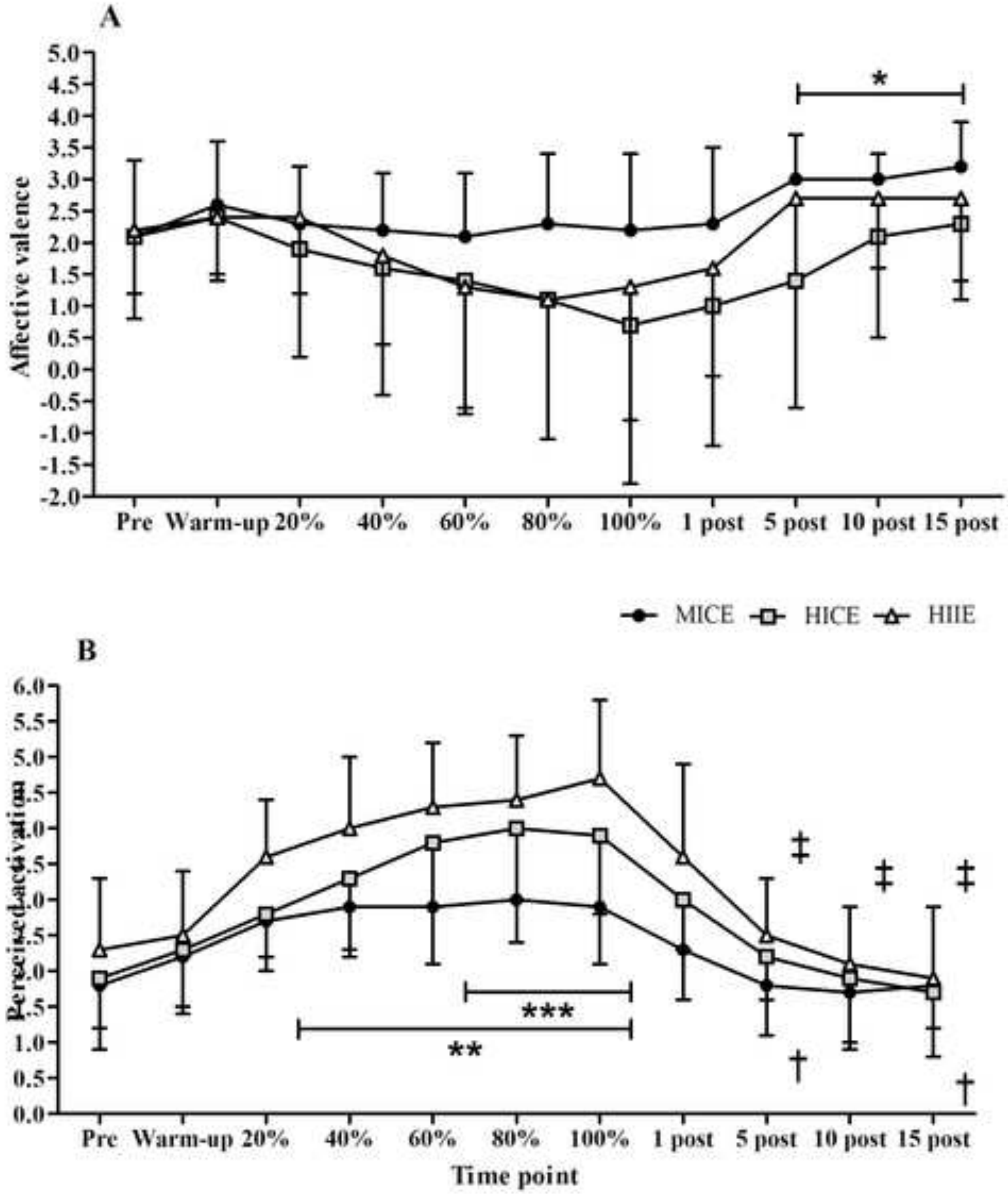
Data are mean ± SD. Power and work in the HIIE trial calculated from sprint bouts only. Peak power in the HIIE trial is the mean of the highest 1 sec average power output from each sprint. Heart rate data in the HIIE trial is mean HR from the beginning of sprint 1 to the completion of sprint 10. Peak HR in the HIIE trial is highest 5 sec average HR attained. * ES not calculated for this comparison due to absence of variation in the two data sets.

Figure

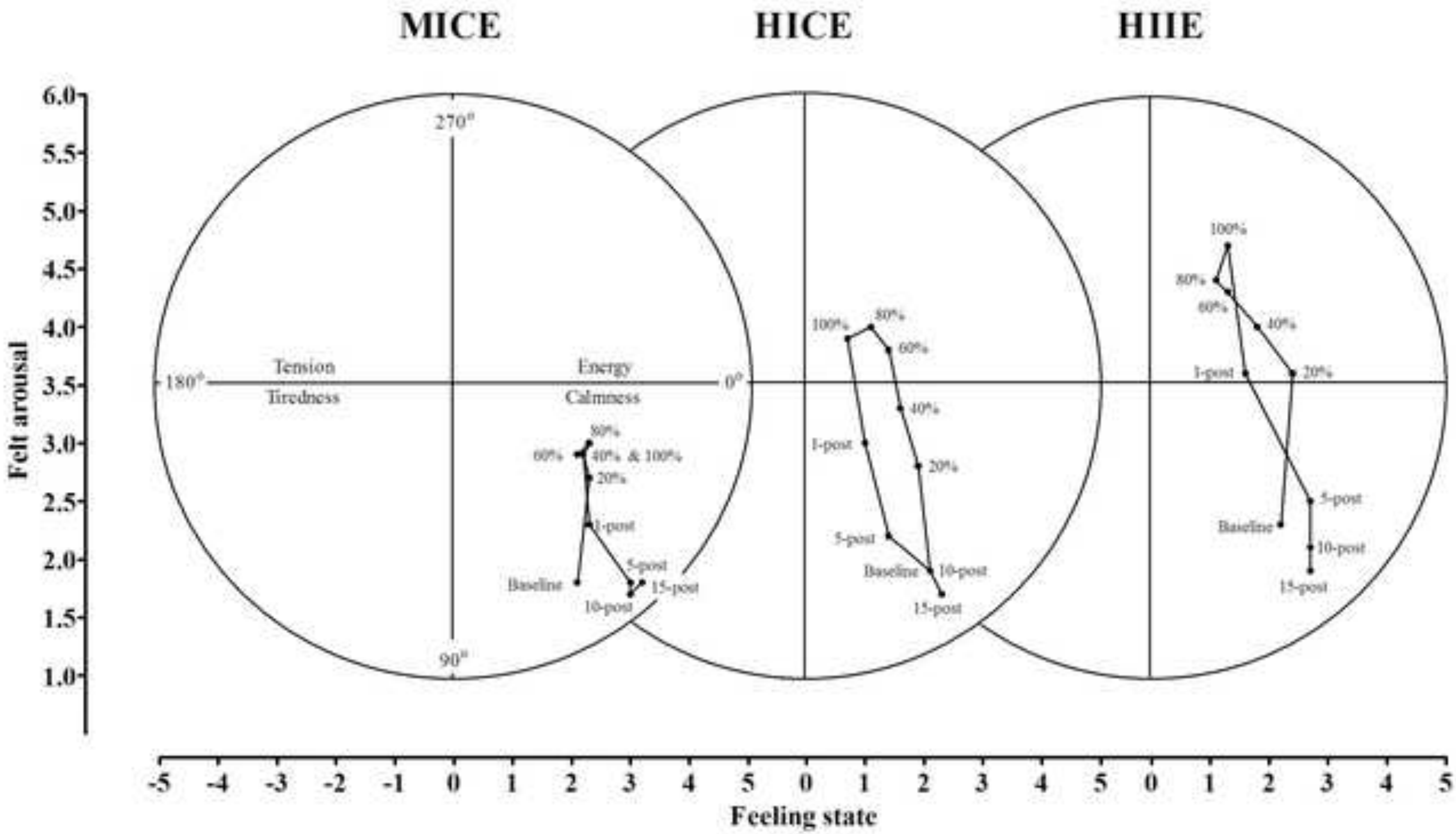


MICE
0
20
40
60
80
100
2
5
10
15
Percentage of exercise completed
Time (min)
HICE
0
20
40
60
80
100
2
5
10
15
Percentage of exercise completed
Time (min)
HIIE
0 20 40 60 80 100 2
5
10
15
Percentage of exercise completed
Time (min)
MICE
HICE
HIIE
0
5
10
15
20
25
30
Exercise time (min)
2 min warm up/cool down
Seated recovery
1 min passive rest
Feeling scale and felt arousal
Constant intensity cycling
Feeling scale, felt arousal, rating of perceived exertion
6 sec cycle sprint

Figure


A
Affective valence
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
Pre
Warm-up
20%
40%
60%
80%
100%
1 post
5 post
10 post
15 post
*
MICE
HICE
HIIE
B
Perceived activation
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
***
**
‡
†
Time point

Figure


MICE
HICE
HIIE
Felt arousal
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
270°
180°
0°
90°
Tension
Tiredness
Energy
Calmness
80%
60%
40% & 100%
20%
1-post
5-post
15-post
Baseline
10-post
100%
80%
60%
40%
1-post
20%
5-post
Baseline
10-post
15-post
100%
80%
60%
40%
1-post
20%
5-post
Baseline
10-post
15-post
-5 -4 -3 -2 -1 0 1 2 3 4 5 0 1 2 3 4 5 0 1 2 3 4 5
Feeling state