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Research article

Perceptual and Cardiorespiratory Responses to High-Intensity Interval Exercise in Adolescents: Does Work Intensity Matter?

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Abstract
High-intensity interval exercise (HIIE) may not elicit prominent unpleasant feelings even with elevated perceived exertion and physiological stress in adolescents. However, the influence of different HIIE work intensities on the affective experience and cardiorespiratory responses is unknown. This study examined the acute affective, enjoyment, perceived exertion and cardiorespiratory responses to HIIE with different work intensities in adolescents. Participants (n = 16; 8 boys; age 12.0 ± 0.3 years) performed, on separate days, HIIE conditions consisting of 8 x 1-minute work-intervals at 70%, 85%, or 100% peak power separated by 75 seconds recovery at 20 W. Affect, enjoyment and rating of perceived exertion (RPE) were recorded before, during, and after HIIE. Heart rate (HR) and oxygen uptake were collected during HIIE. Affect declined in all conditions ($p < 0.01$) but 100%HIIE elicited significantly lower affect than 70%HIIE and 85%HIIE at work-interval 8 (all $p < 0.02$, ES > 1.74; 70%HIIE = 2.5 ± 0.8; 85%HIIE = 1.1 ± 1.5; 100%HIIE = -1.5 ± 1.4 on feeling scale). Similar enjoyment was evident during and after all conditions (all $p > 0.44$). RPE was significantly higher during 100%HIIE than 70%HIIE and 85%HIIE across all work-intervals (all $p < 0.01$, ES > 1.56). The majority of the participants attained ≥90%HR_{max} during 85%HIIE (87%) and 100%HIIE (100%), but not during 70%HIIE (6%). Affect responses during HIIE are dependent on the intensity of the work-interval and are not entirely negative (unpleasant feelings). Despite similar enjoyment, positive affect experienced during 70%HIIE and 85%HIIE could serve as a strategy to encourage exercise adoption and adherence in adolescents, but only 85%HIIE elicits sufficient HR stimulus to facilitate potential health benefits.

Key words: Affective valence, exercise motivation, interval exercise, work intensity, youth.

Introduction

Given that short bouts of vigorous intensity physical activity (PA) may drive numerous health benefits (Barker et al., 2018; Carson et al., 2014; Hay et al., 2012) and the intermittent nature of habitual PA in youth (Bailey et al., 1995), high-intensity interval exercise (HIIE) training has been proposed as a strategy to engage 5-18 year olds in PA (Bond et al., 2017). HIIE training has been shown to enhance cardiometabolic health and cardiorespiratory fitness in youth (Bond et al., 2017; Costigan et al., 2015). However, HIIE protocols utilise work-intervals within the heavy or severe (i.e. exercise above the first ventilatory threshold [VT] up to the level of maximal exercise capacity) exercise intensity domains (Bond et al., 2017; Malik et al., 2017) which may evoke negative affective responses (i.e. feelings of displeasure) and lead to poor exercise adherence (Biddle and Batterham, 2015; Hardcastle et al., 2014). Consequently, the adoption of HIIE to improve the health and well-being of youth is unclear.

The theoretical framework known as the dual mode theory (DMT) explains the exercise intensity-affect relationship during exercise (Ekkekakis et al., 2005) and has been used as an argument against the adoption and maintenance of HIIE training interventions for public health promotion (Biddle and Batterham, 2015). The DMT postulates that in the moderate exercise intensity domain (exercise performed below VT), there is low-to-moderate influence of cognitive factors originating in the frontal cortex of the brain (e.g. self-efficacy), and affect remains homogenously positive (i.e. pleasurable). In the heavy exercise intensity domain (exercise performed between the first VT to the respiratory compensation point (RCP)), there is strong dominance of cognitive factors, with interoceptive cues associated with the physiological strain of exercise (e.g. increased HR) having a modest influence. Hence, affective responses are likely to vary between individuals with some individuals reporting changes toward pleasure, while others may report as unpleasant. In the severe exercise intensity domain (exercise performed above the RCP), there is a strong dominance of interoceptive cues due to the increased dependence of anaerobic sources, where physiological steady state can no longer be maintained, and is associated with homogenously negative affect (i.e. feelings of displeasure) (Ekkekakis et al., 2005).

Previous studies in adolescents have supported the observation of negative affective responses during continuous and incremental exercise when intensity exceeds the VT, in line with the DMT (Benjamin et al., 2012; Stych and Parfitt, 2011). However, recent evidence has reported that a commonly used HIIE protocol in youth (8 x 1 min performed at 90% peak power separated with 75 s active recovery) generates greater enjoyment following HIIE compared to moderate-intensity continuous or interval exercise and does not have prominent negative affective responses (Malik et al., 2017; 2018a). The authors (Malik et al., 2018a) reasoned that the low-intensity exercise performed during the recovery intervals may preserve positive feelings during the HIIE work intervals. However, the HIIE protocol used in the aforementioned studies focused on a single HIIE work intensity (90% peak power), yet a variety of HIIE work intensities (e.g. 70% to 100% of maximal exercise capacities) have been shown to be effective in facil-

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itating health benefits in children and adolescents (Bond et al., 2017). It has been demonstrated in adolescents that HIIE cycling performed at decreasing work intensity (100% to 70% peak power) elicited more pleasurable feelings in affective responses than HIIE cycling performed at increasing work intensity (70% to 100% peak power) (Malik et al., 2018b), suggesting an intensity dependence of the work interval. As proposed by the DMT, increasing the exercise intensity above the VT leads to progressively negative affective responses during exercise (Ekkekakis et al., 2005). Whether affect evaluation is perceived differently during HIIE with different work intensities is currently unknown in adolescents. It is vital to understand the pattern of affective responses during HIIE, as previous research has indicated that the affect experienced during exercise can influence future PA motivation and behaviour in youth (Schneider et al., 2009).

While acute cardiorespiratory (i.e. HR and oxygen uptake [$\dot{V}O_2$]) and perceived exertion (i.e. ratings of perceived exertion [RPE]) responses commonly used in HIIE protocols have been studied in adolescent boys and girls (Malik et al., 2017), the impact of various HIIE work intensities on these outcomes is unknown. Elucidating this information during HIIE is important, as a recent study in adolescent boys reported that the reduced affective responses during HIIE were negatively correlated to physiological (e.g. increased HR) and exertional (i.e. RPE) stress (Malik et al., 2017). Furthermore, HIIE protocols that elicit a sufficient HR stimulus (i.e. ≥90% HR_{max}) to enhance cardiometabolic and fitness health accompanied with pleasurable and enjoyable feelings, may be useful for future exercise programme planning to promote exercise maintenance and elicit health benefits (Schneider et al., 2009; Taylor et al., 2015).

The purpose of this study was to examine the acute affective and enjoyment responses to HIIE with different work intensities (i.e. 70%, 85%, and 100% peak power) during an 8 × 1 min HIIE protocol in adolescent boys and girls. The secondary aim was to describe the acute cardiorespiratory and perceived exertion responses during the HIIE protocols and examine relationships with the affect responses. We hypothesised that affective responses during HIIE would be dependent on work intensity, with HIIE at 100% peak power eliciting less pleasurable feelings than HIIE at 70% and 85% peak power.

Methods

Participants

Sixteen 11-13-year-old adolescents (8 boys) volunteered to take part in the study (see Table 1 for the participants' descriptive characteristics). A brief explanation about this study was given to approximately 50 pupils during a school assembly and 25 information packs (participant information sheet, health screening form, participant assent and parent consent forms) were taken by the pupils. A total of sixteen information packs were returned by the pupils for participation in the study. The size of the sample was based on the ability to detect a medium to large effect in the affective responses using previous published data in youth (Malik et al., 2018a) for a two-way repeated measure ANOVA with an alpha of 0.05 and power of 0.8. This resulted in an indicative sample size of 9 or 18 participants to detect a moderate and large effect respectively. None of the participants presented any condition or illness which could alter mood and exercise performance, and musculoskeletal injury especially to lower limbs, which may prohibit the study testing. Written participant assent and parental/guardian consent were obtained before participation in the project, which was approved by the institutional ethics committee (61207/B/03).

Experimental overview

This cross-over study consisted of four visits to the satellite laboratory in the school, separated by a minimum two-day rest period (mean = 6, SD = 2 days). The first visit was to measure anthropometric variables, determine cardiorespiratory fitness and familiarise participants with the measurement scales. This was followed by three experimental visits each involving a cycling HIIE protocol with a different work intensity (70%, 85% and 100% peak power), the order of which was counterbalanced to control for an order or learning effect. Participants performed the exercise test at the same time of the day between the hours of 08:00 to

Table 1. Descriptive characteristics of the participants (n = 16).

	Boys (n = 8)	Girls (n = 8)	P- value	ES
Age (y)	12.5 ± 0.3	12.8 ± 0.5	0.22	0.73
Body mass (kg)	43.5 ± 9.9	45.3 ± 8.2	0.69	0.20
Stature (m)	1.58 ± 0.09	1.55 ± 0.08	0.50	0.35
BMI ($kg \cdot m^{-2}$)	18.1 ± 1.9	18.1 ± 3.6	0.99	0.00
Body fat (%)	13.9 ± 4.8	21.4 ± 8.5	**0.04**	1.09
MVPA per day (min)*	32 ± 6	27 ± 7	0.23	0.77
HR_{max} (bpm)	194 ± 4	190 ± 8	0.18	0.63
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	1.73 ± 0.19	1.61 ± 0.18	0.21	0.65
$\dot{V}O_{2max}$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	39.9 ± 5.3	35.4 ± 3.1	0.19	0.69
HR at VT (bpm)	151 ± 8	145 ± 7	0.17	0.80
VT (%HR_{max})	77 ± 5	76 ± 9	0.15	0.14
RPE_{max}	8 ± 1	7 ± 1	0.33	0.49
RPE at VT	5 ± 1	5 ± 1	0.37	0.00
VT ($L \cdot min^{-1}$)	0.99 ± 0.22	0.75 ± 0.10	**0.01**	1.40
VT (%$\dot{V}O_{2max}$)	57.0 ± 9.4	46.4 ± 3.9	**0.01**	1.47

Values are reported as mean ± standard deviation. Abbreviations: BMI, body mass index; MVPA, moderate to vigorous physical activity; $\dot{V}O_{2max}$, maximal oxygen uptake; HR_{max}, maximal heart rate; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; VT, ventilatory threshold; RPE_{max}, maximal rating of perceived exertion. * Physical activity data are presented for 15 participants (8 boys).

13:00. All exercise tests were performed on an electronically braked cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands).

Anthropometric, maturation offset and physical activity measures

Body mass and stature were measured to the nearest 0.1 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated as body mass (kg) divided by stature (m) squared. Age and sex specific BMI cut-points for overweight and obesity status were determined from Cole et al. (2000). Percentage body fat was determined using triceps and subscapular skinfolds measured to the nearest 0.2 mm (Harpenden callipers, Holtain Ltd, Crymych, UK), according to sex and maturation specific equations (Slaughter et al., 1988). The ratio standard method to scale for body mass was used to define low cardiorespiratory fitness as indicative of increased cardiometabolic risk based on age and sex specific aerobic fitness cut-offs in youth (Adegboye et al., 2011). Finally, maturation (somatic) offset from the age at peak height velocity was determined from participant age and stature using the modified equation of Moore et al. (2015). Earlier maturing participants were defined as the offset score <-1 year, typical maturing participants were defined as the offset score between -1 to 1 year and late maturing participants were defined as the offset score >+1 year.

After completion of the HIIE protocols, participants' daily habitual PA was measured for seven consecutive days using wrist accelerometers (GENEActiv, GENEA, UK) on their non-dominant hand. Participants' data were used if they had recorded ≥10 hours/day of wear time for at least three week days and one weekend day (Riddoch et al., 2007). The validity and reliability of the accelerometer has been established previously in children and adolescents (Phillips et al., 2013). Data were collected at 100 Hz and analysed at 1 s epoch intervals to establish time spent in moderate and vigorous intensity PA using a cut-off point of ≥1140 counts per minute previously validated in youth (Phillips et al., 2013). In this study, accelerometer data were available on 15 participants (8 boys); one participant was excluded due to insufficient data.

Cardiorespiratory fitness

Participants were familiarised to exercise on the cycle ergometer before completing a ramp test to establish maximal oxygen uptake ($\dot{V}O_{2max}$) and the first VT (Barker et al., 2011). Participants began a warm-up of unloaded cycling for 3 min, followed by cycling at a cadence between 75-85 rpm with 15 W increments every 1 min until volitional exhaustion, before a 5 min cool down at 25 W. Exhaustion was defined as a drop in cadence below 60 rpm for 5 consecutive seconds despite strong verbal encouragement.

HIIE protocols

Participants performed the HIIE protocols consisting of a 3 min warm-up at 20 W followed by 8 x 1 min work intervals at either 70% (70%HIIE), 85% (85%HIIE) or 100% (100%HIIE) of the peak power determined from the ramp test, interspersed with 75 s active recovery at 20 W. A 2 min cool down at 20 W was provided at the end of the protocol. The HIIE protocols were matched for total exercise duration which includes the duration of work and recovery intervals, warm-up and cool down sessions (i.e. 22 min 15 s).

Experimental measures

Gas exchange and heart rate

Pulmonary gas exchange and HR were measured continuously using a calibrated metabolic cart (Cortex Metalyzer III B, Leipzig, Germany) and telemetry system (Polar Electro, Kempele, Finland), respectively. Both gas exchange and HR data were subsequently averaged over 10 s intervals. The VT was estimated at the point where the first disproportionate increase in CO_2 production compared to $\dot{V}O_2$ occurred and verified using the ventilatory equivalents for carbon dioxide production ($\dot{V}CO_2$) and $\dot{V}O_2$. $\dot{V}O_{2max}$ and maximal HR (HR_{max}) were accepted as the highest 10 s average in $\dot{V}O_2$ and HR elicited during the ramp test. A cut-point of ≥90 % HR_{max} was used as our criterion for satisfactory compliance to the HIIE protocol (Malik et al., 2017; Taylor et al., 2015).

Affective responses

Affective valence (pleasure/displeasure) was measured using the feeling scale (FS; Hardy and Rejeski, 1989) according to previous work in adolescents (Benjamin et al., 2012; Malik et al., 2017; Stych and Parfitt, 2011). Participants responded to how they felt on an 11-point bipolar scale ranging from "Very Good" (+5) to "Very Bad" (-5). Perceived activation levels were measured using the single-item felt arousal scale (FAS; Svebak and Murgatroyd, 1985). Participants were asked to rate themselves on a 6-point scale ranging from 1 'low arousal' to 6 'high arousal'. FS and FAS exhibited correlations ranging from 0.41 to 0.59 and 0.47 to 0.65, respectively, with the Affect Grid (Russell et al., 1989), indicative of convergent validity with similar established measures (Van Landyut et al., 2000).

Affective responses were also assessed from the perspective of the circumplex model (Russell et al., 1989), using a combination of FS and FAS. The circumplex is divided into 4 quadrants, each characteristic of different affective states: 1) unactivated/pleasant affect (e.g. calmness and relaxation); 2) unactivated/unpleasant affect (e.g. boredom or fatigue); 3) activated/unpleasant affect (e.g. tension or nervousness); and 4) activated/pleasant affect (e.g. excitement or happiness).

Perceived enjoyment

Participants rated their enjoyment during the exercise conditions on a 7-point exercise enjoyment scale (EES; Stanley and Cumming, 2010) according to previous work in adolescents (Malik et al., 2018a; 2018b). Participants were instructed to respond to the statement "Use the following scale to indicate how much you are enjoying this exercise session", ranging from 1 (not at all) to 7 (extremely). EES exhibits correlations ranging from 0.41 to 0.49 with FS, indicative of convergent validity with similar established measurers (Stanley et al., 2010). Post-enjoyment was measured using the modified physical activity enjoyment scale (PACES), which is validated for use in adolescents (Motl et al., 2001). The PACES includes 16 items that are rated on a 5-point bipolar scale (score 1 = "strongly disagree" to score 5 = "strongly agree").

Rating of perceived exertion

RPE was assessed using the validated 0–10 Pictorial Children's OMNI scale (Robertson et al., 2000). Participants were instructed to respond to the statement "How tired does your body feel during exercise" via a 0-10 point Likert item ranging from 0 (not tired at all) to 10 (very, very tired).

Measurement time points

Participants were given standardised verbal instructions on how to use the scales in visit one and before undertaking the HIIE protocols. They were asked to provide their verbal responses at 5 min before the exercise protocol (FS and FAS), 20 s before the end of the warm-up session (as following order- FS, FAS, EES and RPE), 20 s before the end of each work and recovery interval (as following order- FS, FAS, EES and RPE), immediately post-exercise (FS, FAS, EES, RPE and PACES) and 20 min post-exercise (FS, FAS and PACES). FS, FAS and RPE were also obtained at the end of every stage during the incremental exercise to exhaustion (visit one) to familiarise the participants with the scales. All the scales were administered by the same researcher.

Statistical analysis

All statistical analyses were conducted using SPSS (SPSS 24.0; IBM Corporation, Armonk, NY, USA). Descriptive characteristics (mean ± standard deviation) between boys and girls were analysed using independent samples t-tests. Data were analysed using a mixed model analysis of variance (ANOVA) to examine sex differences in affect, enjoyment, RPE and cardiorespiratory data between HIIE the protocols (70%, 85% and 100% peak power) over time (the work and recovery intervals) and experimental orders (prescribed first, second or third). The inclusion of sex into the ANOVA model did not reveal a significant interaction effect for affect, enjoyment, RPE and cardiorespiratory fitness during all conditions. Data were subsequently pooled for these outcomes. A series of one-way repeated measure ANOVAs were also conducted to examine the magnitude of changes from baseline across the work intervals in affect, enjoyment and RPE responses within each HIIE protocol. Where sphericity was violated, Greenhouse-Geisser was used to adjust the degrees of freedom and these are reported. In the event of significant effects ($p < 0.05$), follow-up Bonferroni post hoc tests were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using effect size (ES) calculated using Cohen's *d* (Cohen, 1988), where an ES of 0.20 was considered to be a small change between means, and 0.50 and 0.80 interpreted as a moderate and large change, respectively. Pearson's product-moment correlation coefficient was used to examine the relationships of enjoyment, RPE and HR responses with affect responses during the work intervals.

Results

The participants' descriptive characteristics are presented in Table 1. Twelve participants (7 boys, 5 girls) were deemed to have a level of fitness indicative of increased cardiometabolic risk. One participant was categorised as overweight and the rest were normal weight. A total of four boys were categorised as a late maturers (<-1 of maturation offset) and three girls were categorised as earlier maturers (>+1 of maturation offset). The remaining of nine participants were categorised as typical maturers. One boy was achieving the recommended guideline of 60 min of daily MVPA. The inclusion of experimental orders into the ANOVA model did not reveal a significant interaction effect for all outcomes (all $P>0.53$), showing that the counterbalance order did not influence affect, enjoyment, RPE and cardiorespiratory responses in this present study.

Cardiorespiratory responses

The cardiorespiratory data from the exercise conditions for boys and girls are presented in Table 2. There was a significant condition by interval number interaction for absolute and relative HR (all $p < 0.01$), with the average HR during 70%HIIE lower than 85%HIIE (ES = 2.40) and 100%HIIE (ES = 3.00). There were significant increases in HR across consecutive work intervals for all HIIE conditions (all $p < 0.01$, ES > 0.21). During 70%HIIE, one girl reached the cut-off point of ≥90 % HR_{max} which occurred during work intervals 6 to 8. During 85%HIIE, 12 participants (7 girls) reached the cut-off point of ≥90 % HR_{max}

Table 2. Cardiorespiratory responses to HIIE with different intensities.

	HIIE70%	HIIE85%	HIIE100%
Peak power (W)	87.4 ± 12.2 #†	106.1 ± 14.8 *†	124.8 ± 17.4 *#
Average HR (bpm)	141 ± 8 #†	157 ± 5 *	160 ± 4 *
Average HR (% HRmax)	73 ± 5 #†	82 ± 3 *	83 ± 4 *
Peak HR (bpm)	161 ± 6 #†	181 ± 4 *†	184 ± 2 *#
Peak HR (%HRmax)	83 ± 4 #†	94 ± 4 *†	96 ± 6 *#
Average $\dot{V}O_2$ (L·min^{-1})	0.86 ± 0.10 #†	0.99 ± 0.08 *	1.03 ± 0.08 *
Average $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	51 ± 7 #†	60 ± 5 *	62 ± 8 *
Peak $\dot{V}O_2$ (L·min^{-1})	1.21 ± 0.19 #†	1.35 ± 0.07 *	1.38 ± 0.04 *
Peak $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	73 ± 16 #†	81 ± 10 *	83 ± 15 *

Values are reported as mean ± standard deviation. Abbreviations: HR, heart rate; HR_{max}, maximal heart rate; $\dot{V}O_2$, oxygen uptake: $\dot{V}O_{2max}$, maximal oxygen uptake; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; VT, ventilatory threshold.
* Significant difference between 70%HIIE ($p < 0.01$). # Significant difference between 85%HIIE ($p < 0.01$). † Significant difference between 100%HIIE ($p < 0.01$).

which occurred during work intervals 4 to 8. During 100%HIIE, all participants reached the cut-off point of ≥90 % HR_{max} which typically occurred during HIIE work intervals 3 to 8. Based on the VT representing ~ 52% $\dot{V}O_{2max}$, the prescribed HIIE protocols were performed at an intensity that exceeded the VT for work intervals 1 to 8 (i.e. 70%HIIE = 56% to 66% $\dot{V}O_{2max}$; 85%HIIE = 70% to 77% $\dot{V}O_{2max}$; 100%HIIE= 72% to 78%). All participants completed the HIIE protocols and no adverse events were observed.

Affective responses

FS responses during the three HIIE conditions are illustrated in Figure 1A. FS showed a significant condition by interval number interaction effect ($p < 0.01$). FS was significantly higher during 70%HIIE than 85%HIIE at work intervals 5 to 8 ($p < 0.01$, ES = 0.72 to 1.17) and at recovery interval 7 ($p = 0.03$, ES = 1.00). FS was also significantly higher during 70%HIIE than 100%HIIE for all work ($p < 0.004$, ES=1.09 to 3.47) and recovery ($p < 0.002$, ES = 1.18 to 2.73) intervals. Finally, FS was significantly higher during 85%HIIE than 100%HIIE for all work intervals ($p < 0.02$, ES = 0.70 to 1.74) and at recovery intervals 4 to 7 ($p < 0.003$, ES = 1.26 to 1.35). FS declined during the work (all $p < 0.01$) and recovery (all $p < 0.04$) intervals in all HIIE protocols. During 70%HIIE, FS significantly decreased from 5-min pre at work intervals 6 to 8 ($p < 0.04$; ES = 1.03 to 1.27) and at recovery intervals 6 to 7 ($p < 0.029$; ES = 0.70 to 0.83). During 85%HIIE the decrease from 5-min pre was significant at work and recovery intervals 3 to 8 (work, $p < 0.009$; ES = 0.72 to 1.97; recovery, $p < 0.007$; ES = 0.63 to 1.45). During 100%HIIE the decrease from 5-min pre was significant across all intervals (work, $p < 0.003$; ES = 1.25 to 4.04; recovery, $p < 0.007$; ES =1.22 to 2.92). FS remained positive at work-interval 8 during 70%HIIE (2.5 ± 0.8) and 85%HIIE (1.1 ± 1.5) in all (100%) and 14 participants (87%), respectively. In contrast, 100%HIIE elicited a negative FS score at work-interval 8 (-1.5 ± 1.4) in 14 participants (87%). Correlations between FS and HR during the HIIE protocols are illustrated in Figure 2A. A strong negative relationship was observed between absolute HR and %HRmax and with FS during the work intervals in 70%HIIE (all $p < 0.01$, $r = -0.94$), 85%HIIE (all $p < 0.01$, $r = -0.95$) and 100%HIIE (all $p < 0.01$, $r = -0.98$).

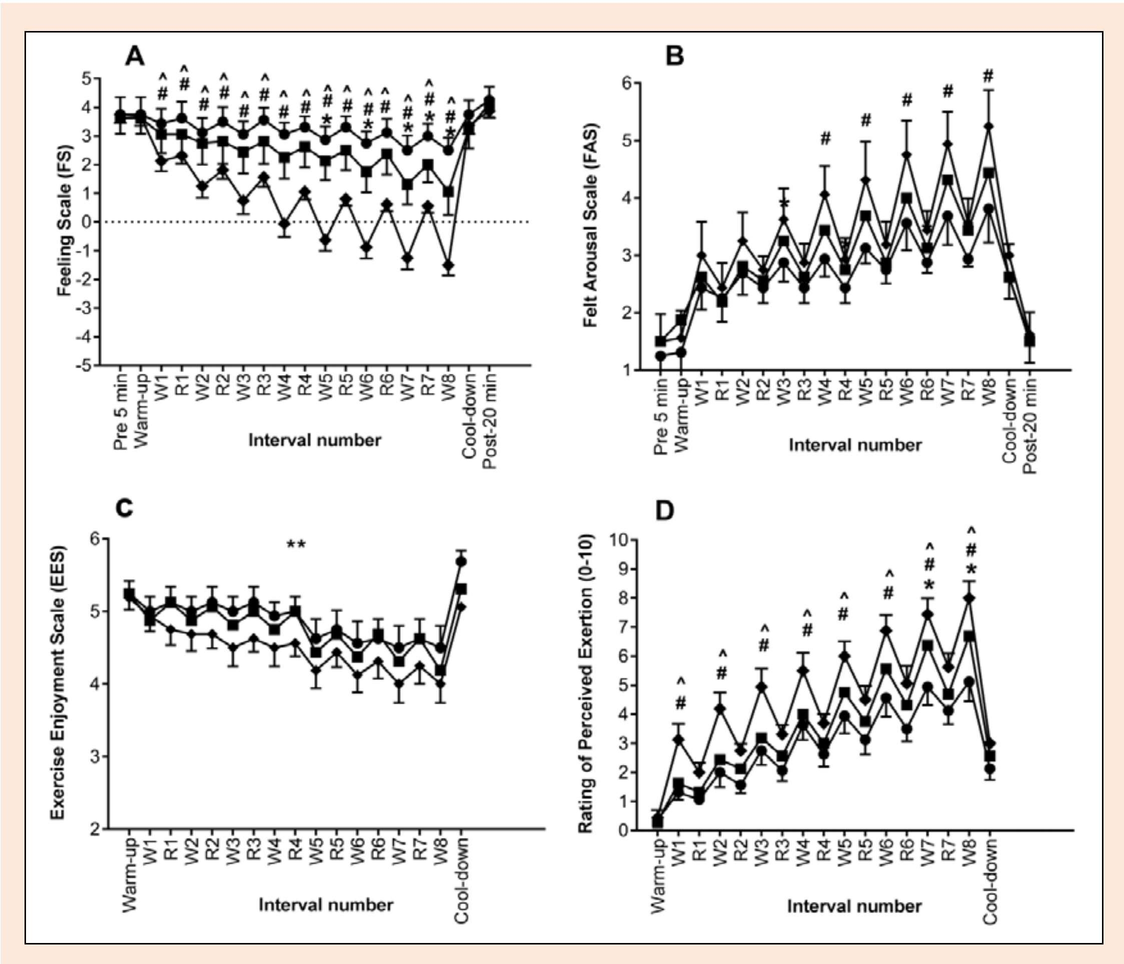

Figure 1. Feeling scale (A), felt arousal scale (B), exercise enjoyment scale (C) and rating of perceived exertion (D) during the interval and recovery phases of the 70%HIIE (●), 85%HIIE (■) and 100%HIIE (♦). Where, W= work interval and R= recovery interval. * Significant difference between 70%HIIE and 85%HIIE. # Significant difference between 70%HIIE and 100%HIIE. ^ Significant difference between 85%HIIE and 100%HIIE.** Significant main effect for interval number. Error bars are presented as SD. See text for details.

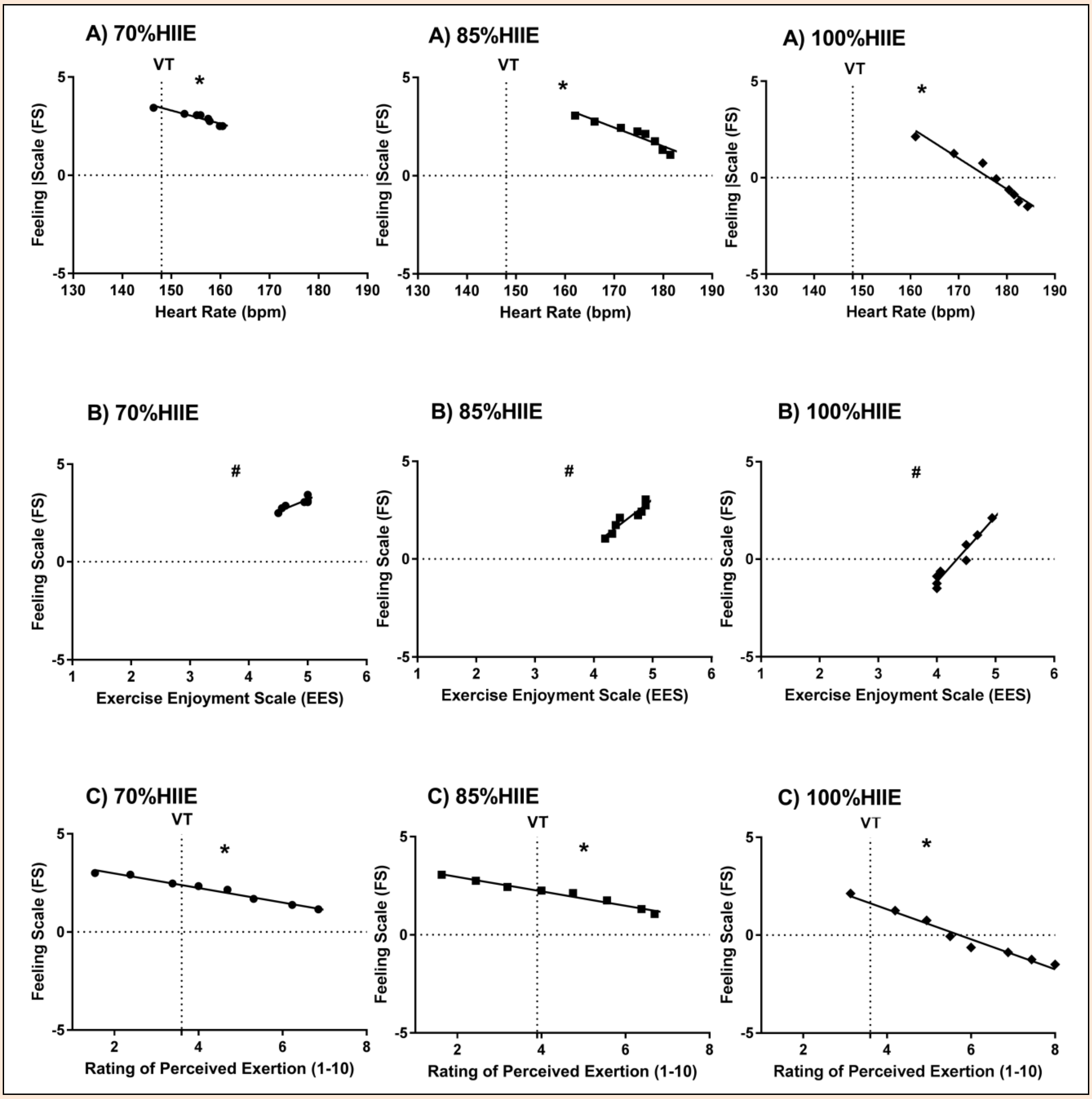

Figure 2. Correlation analysis between Feeling scale (FS) and heart rate (A), exercise enjoyment scale (B) and rating of perceived exertion (C) during 70%HIIE (●), 85%HIIE (■) and 100%HIIE (♦) work intervals. Abbreviations: Ventilatory threshold (VT), which is denoted by the vertical dotted line. * Significantly negative correlations. # Significantly positive correlations. See text for details.

FAS responses during the HIIE protocols are illustrated in Figure 1B. FAS showed a significant condition by interval number interaction ($p = 0.04$). FAS was significantly lower during 70%HIIE than 100%HIIE at work intervals 4 to 7 ($p < 0.02$; ES = 1.45 to 1.26) but no significant differences between recovery intervals (all $p > 0.07$). No significant differences were evident during work and recovery intervals between 70%HIIE and 85%HIIE (all $p > 0.06$). FAS increased during the work intervals for all conditions (all $p < 0.01$). Specifically, the increase from the 5-min pre was significant at work intervals 1 to 8 for all HIIE protocols ($p < 0.01$; 70%HIIE, ES = 1.29 to 2.68; 85%HIIE, ES = 1.40 to 2.95; 85%HIIE, ES = 1.51 to 3.59).

Affective responses (valence and activation) during the work and recovery intervals for HIIE protocols were plotted onto a circumplex model (Figure 3). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant for the 70%HIIE and 85%HIIE work intervals, but affective responses remained in the unactivated/pleasant quadrant for their HIIE recovery intervals. During 100%HIIE, the affective responses shifted from unactivated/pleasant to the activated/unpleasant quadrant for the work intervals, and from unactivated/pleasant to the activated/pleasant quadrant for the 100%HIIE recovery intervals.

Exercise enjoyment responses

The enjoyment responses during the HIIE protocols are illustrated in Figure 1C. There was no condition by time interaction ($p = 0.38$) or main effect of condition ($p < 0.33$; 70%HIIE vs. 85%HIIE, ES at work intervals 1 to 8 = 0.13 to 0.22; 70%HIIE vs. 100%HIIE, ES = 0.14 to 0.34; 85%HIIE vs. 100%HIIE, ES = 0.06 to 0.14), but there was a main effect of time ($p < 0.01$) for EES. EES declined during the work intervals for all HIIE conditions (all $p < 0.02$). In 70%HIIE and 85%HIIE conditions, the decline from warm-up was significant from work intervals 6 to 8 (all $p < 0.03$; 70%HIIE, ES = 0.40 to 0.48; 85%HIIE, ES = 0.43 to 0.52). In contrast, during 100%HIIE, the decline from warm-up was significant from work intervals 3 to 8 ($p = 0.004$; ES = 0.47 to 1.00). There was a strong positive correlation between ESS and the FS responses for all HIIE conditions ($p < 0.01$, $r > 0.90$).

There was no condition by time interaction ($p = 0.68$) or main effect of condition ($p = 0.31$; 70%HIIE vs. 85%HIIE, ES = 0.10 (immediately) and ES = 0.09 (20-min after); 70%HIIE vs. 100%HIIE, ES = 0.15 (immediately) and 0.30 (20-min after); 85%HIIE vs. 100%HIIE, ES = 0.29 (immediately) and 0.36 (20-min after)), but there was a main effect of time ($p = 0.001$) for PACES. PACES was significantly higher 20-min after compared to immediately after HIIE in all conditions (70% HIIE, 75 ± 2 vs. 72 ± 5, $p = 0.01$, ES = 0.79; 85%HIIE, 75 ± 3 vs. 73 ± 4, $p = 0.002$, ES = 0.57; 100%HIIE, 74 ± 3 vs. 71 ± 3, $p = 0.02$, ES = 1.00, respectively). No differences were observed for PACES between the HIIE conditions immediately and 20-min after HIIE (all $p > 0.44$). Also, there was a positive correlation between the FS at the work interval 8 and PACES score immediately after and 20 min after in 70%HIIE ($p = 0.01$, $r = 0.62$; $p = 0.01$, $r = 0.66$) and 85%HIIE ($p = 0.04$, $r = 0.54$; $p = 0.04$, $r = 0.57$), but not in 100%HIIE ($p = 0.25$, $r = 0.31$; $p = 0.77$, $r = 0.18$).

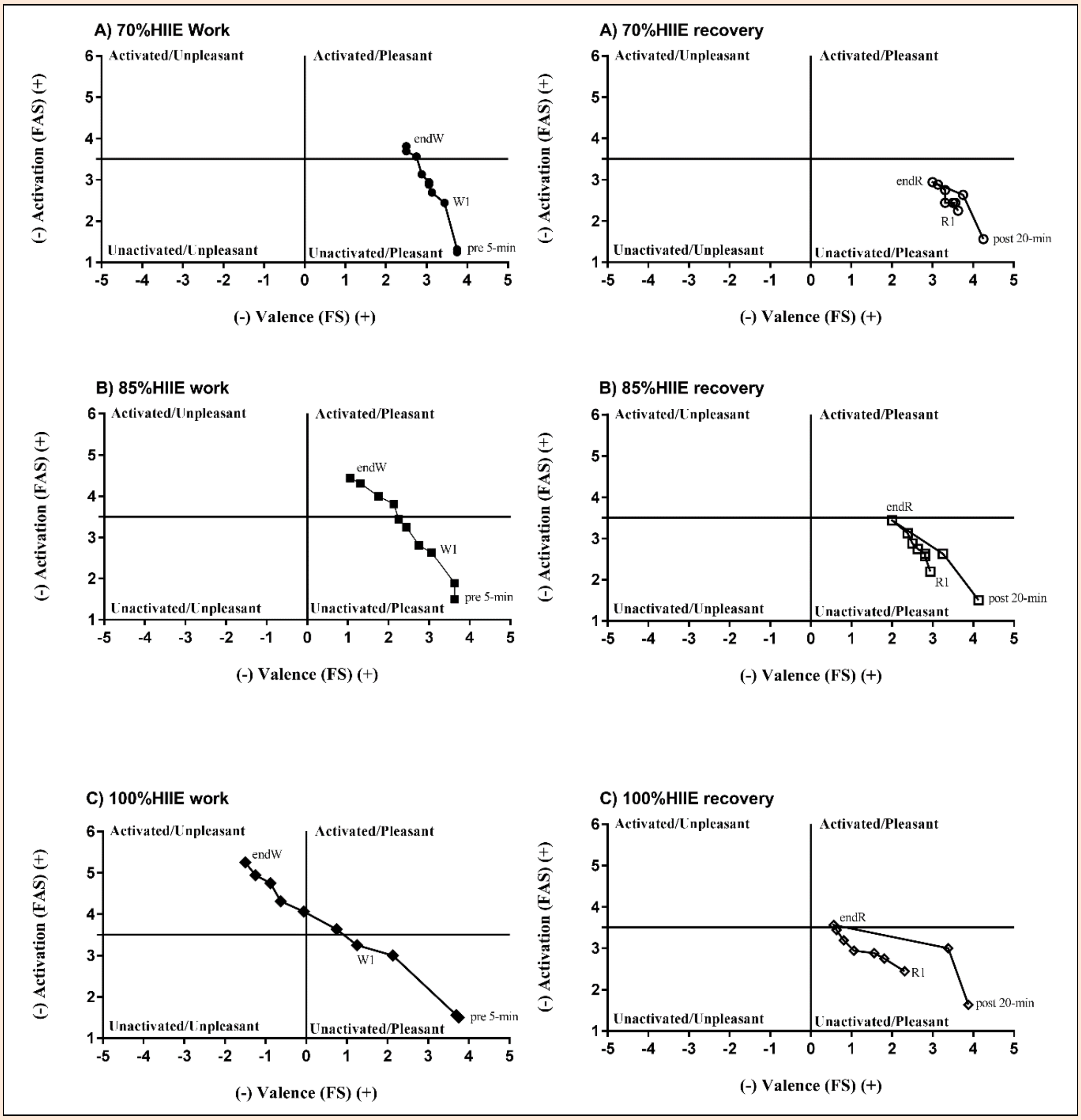

Figure 3. **Valence (FS) and activation (FAS) during the work and recovery interval of 70%HIIE (A), 85%HIIE (B) and 100%HIIE (C) plotted onto the circumplex model. 70%HIIE work interval (●), 85%HIIE work recovery interval (■) and 100%HIIE work interval (♦); 70%HIIE recovery interval (○), 85%HIIE recovery interval (□) and 100%HIIE recovery interval (◊).** Where, W= work interval, R= recovery interval, endW= work interval 8 in HIIE, and endR= recovery interval 7 in HIIE. See text for details.

RPE responses

The RPE responses during HIIE are illustrated in Figure 1D. RPE showed a significant condition by interval number interaction ($p < 0.01$). RPE was significantly higher during 100%HIIE than 70%HIIE for all work intervals (all $p < 0.01$, ES = 2.27 to 2.44) and significantly higher during 100%HIIE than 85%HIIE for all work intervals (all $p < 0.01$, ES = 1.56 to 1.21). RPE was also significantly higher during 85%HIIE than 70%HIIE at work intervals 7 to 8 (all $p < 0.01$, ES = 1.18 to 1.34). RPE increased during the work interval in all HIIE conditions ($p < 0.01$). There was a strong negative correlation between RPE and FS responses during all conditions (all $p < 0.01$; 70%HIIE, $r = -0.95$; 85%HIIE, $r = -0.98$; 100%HIIE, $r = -0.99$).

Discussion

The key findings from this study are: 1) HIIE elicited a decline in affective valence in all HIIE conditions, but remained positive at the end of 70%HIIE and 85%HIIE in the majority of participants (100% and 87%, respectively). In contrast, 100%HIIE evoked negative affective valence at the end work interval in the majority of participants (87%); 2) no significant differences were found between all HIIE conditions for enjoyment responses during and after exercise; 3) affect was correlated with HR (negatively), enjoyment (positively) and RPE (negatively) during HIIE work intervals for all conditions; 4) the majority of the participants reached the cut-off point of ≥90% HR_{max} during 85%HIIE (87% of participants) and 100%HIIE (100% of participants), but not during 70% HIIE (6% of participants).

In this present study, we found a significantly lower and greater decline in affect responses during work and recovery intervals in 100%HIIE compared 70%HIIE and 85%HIIE, showing that an increase in the work intensity generates less pleasurable feelings during HIIE protocols in youth, as predicted by the DMT. Consistent with recent HIIE work in adolescents (Malik et al., 2018a), we observed a more positive affect during HIIE recovery intervals than the work intervals for all conditions (see Figure 1A), which indicate that the recovery interval may be preserving the pleasurable feelings during HIIE. This is in accordance with the rebound model (Bixby et al., 2001), which predicts that a positive affect can occur during rest periods (i.e. low intensity exercise) after an aversive stimulus generated during work periods (i.e. high intensity exercise). We therefore reason that negative affect responses during 100%HIIE in the current study is likely to account for the greater reduction in affect responses in the recovery interval during 100%HIIE. Although the majority of our participants (>87%) reported positive (i.e. 70%HIIE and 85%HIIE) and negative affect (i.e. 100%HIIE) responses at the end HIIE work interval, the evaluation of individual differences in cognitive (e.g. self-efficacy) and exercise experience (e.g. active vs inactive individuals) factors are needed in future research to explain the observed inter-individual variation.

Consistent with the study hypotheses and previous HIIE studies (Boyd et al., 2013; Thackray et al., 2016), affective valence measured by FS scores during 100%HIIE generated negative affect responses. For example, Thackray et al. (2016) found negative feelings (i.e. -2 ± 3 on FS) at the end of HIIE incorporating 5 or 10 × 1 min running intervals at 100% maximal aerobic speed separated by 1 min recovery in adolescent girls. Boyd et al. (2013) found significantly lower affect scores (less pleasurable) during HIIE performed at 100% peak power compared to HIIE performed at 70% peak power in overweight/obese adults. The temporal pattern (i.e. interval by interval basis) and the magnitude changes (i.e. affect changes during exercise from baseline) of affective evaluations during HIIE in these studies are unclear, however (Bixby et al., 2001; Ekkekakis and Petruzzello, 1999). Although 100%HIIE evoked positive affect during the earlier work intervals in the current study, the greater reduction from baseline (i.e. 5 min pre) that initially occurred at the first work interval (ES = 1.25) may have led to a significantly lower affect at the end of the 100%HIIE work interval compared to 70%HIIE (ES=1.03, initially occur at work interval 6) and 85%HIIE (ES=0.72, initially occur at work interval 3). This is in line with Parfitt and Eston (1995), which reveals that at early stages of high-intensity exercise, the work stimulus (i.e. exercise intensity) may not be sufficient enough to generate negative feelings, but the reduction in the affect responses continues until completion of the exercise.

Mechanistic pathways underlying HIIE-induced affective responses are not available for the current study. Recent work in adolescents has speculated, however, that a lower and greater decline in affective valence in HIIE compared with moderate-intensity interval exercise may be related to the influence of HR and/or perceived exertion on affective responses during the work interval (Malik et al., 2018a). As postulated by the DMT, during high-intensity exercise, a deregulation of the prefrontal cortex (PFC) may occur due to the challenge from the augmented physiological variables associated with metabolic strain (i.e. HR, ventilation rate), resulting in a negative affective response, mainly driven by the amygdala (Ekkekakis et al., 2005). Malik et al. (2018a) propose that increases in HR across HIIE work intervals may intensify the body's physiological and exertional stress and potentially generate burning/pain sensations, thus leading to a less positive affect experienced during HIIE. This notion is further supported via the positive correlation between affect with HR and RPE across all conditions in the present study. Our findings also revealed similar average HR responses between 85%HIIE and 100%HIIE across the work intervals (see Table 1) but 100%HIIE elicited higher perceived exertion than 85%HIIE. This raises the possibility that the greater decline in affective responses elicited during 100%HIIE compared with 85%HIIE is not due to physiological factors (i.e. increase in HR) per se, but also due to the greater exertional stress (i.e. feelings of physical stress and fatigue) during 100%HIIE relative to 85%HIIE, as reported by Oliveira et al. (2015).

In this present study we observed an increase in activation (measured by FAS) responses from work interval 1 to 8, accompanied by a decrease in affective valence in all HIIE conditions. This finding is in agreement with the work of Malik et al. (2018a) who also found significant increases in activation with further decreases in affect during subsequent HIIE work intervals performed at 90% maximal aerobic speed. However, we found 100%HIIE exhibited a greater increase in activation (ES = 1.51 to 3.59) compared with 85%HIIE (ES = 1.40 to 2.95) and 70%HIIE (ES = 1.29 to 2.68) (see Figure 1B). Research has shown that during high-intensity exercise, the continued increase in activation was coupled with a marked shift towards negative affective responses (Hall et al., 2002). We reason therefore, that the greater increase in activation during 100%HIIE accompanied by a steep decline in affect is likely to account for the feelings of distress and tension observed in the circumplex model but not during 70%HIIE and 85%HIIE (generate feelings of excitement). Thus, it appears that a 'critical threshold' is reached between 85-100% peak power where the activation becomes progressively higher and affect progressively less positive.

Despite similar enjoyment during HIIE in all conditions, we found a moderate decline in EES scores from warm-up during both 70%HIIE (ES = 0.40 to 0.48) and 85%HIIE (ES = 0.43 to 0.52) after the sixth work interval, but a large reduction in EES scores during 100%HIIE after the third work interval (ES = 0.47 to 1.00). Our findings extend recent work involving HIIE performed at 90% maximal aerobic speed in adolescent boys (Malik et al., 2018a) by showing that enjoyment levels were maintained over the initial ~50% of the total work during 70%HIIE and 85% HIIE, but not for 100%HIIE. In regard to the post-enjoyment responses, we found a positive correlation between the PACES scores (i.e. immediately after and 20 min after) and affect measured at work interval 8 following 70% HIIE and 85%HIIE, but not during 100%HIIE. This observation is consistent with previous work by Decker and Ekkekakis (2016) who reported that greater post-enjoyment in moderate-intensity continuous exercise than HIIE was significantly correlated to the affect responses at the end of the exercise bouts in inactive obese women. This is in line with the peak end rule model (Fredrickson and Kahneman, 1993; Parfitt and Hughes, 2009), which predicts that people tend to place greater emphasis on the peak and the ending of the affect experiences that occurred during the behaviour.

We observed an increase in HR during HIIE in all conditions, which is consistent with previous HIIE studies in adolescents (Malik et al., 2017; Thackray et al., 2016). Although data on health related outcomes are not available in the present study, previous studies have proposed using a cut-off point of ≥90% HRmax to serve as the criterion for compliance with the HIIE protocol to improve cardiometabolic and fitness health in youth (Malik et al., 2017; Taylor et al., 2015). However, only HIIE performed at 85% or 100% peak power elicited a maximal cardiorespiratory response based on the cut-off point of ≥90% HRmax in the majority (~87%) of adolescents. Implications of using HIIE performed at 100% peak power must be taken with caution, however, as this protocol evoked unpleasant feelings (i.e. greater decline from baseline and negative affect experienced) and higher exertional stress, which could lead to avoidance of this protocol in the future. It is important to note that 70%HIIE and 85%HIIE also elicited a decline in affect responses from baseline which occur after work interval 6 and 3, respectively, indicating less pleasurable feelings towards the end of exercise. Data available, however, showing a gradual decline of affect responses during exercise regardless of the intensity (moderate vs. high) and type (interval vs. continuous) of exercise in youth (Stych and Parfitt, 2011; Malik et al., 2018a). Given that affect responses remained positive at the end work interval in 70%HIIE and 85%HIIE, it is plausible to suggest that 70%HIIE and 85%HIIE could improve HIIE implementation, adoption and maintenance in adolescents. Indeed, the peak (positive vs. negative) and end affect are the most consequential stimulus (Fredrickson and Kahneman, 1993), and both are representative of the overall interpretation of an exercise session (Parfitt and Hughes, 2009; Hargreaves and Stych, 2013) to predict future adherence (Rhodes and Kates, 2015). However, it appears that HIIE performed at 85% peak power seems to provide the most favourable HIIE protocol to be acquired in adolescents, at least in the context of the current study, when taking into account the positive affect and HR stimulus to facilitate sufficient health benefits.

One of the strengths of this study relates to the study sample. The majority of our participants had low cardiorespiratory fitness and were insufficiently active which could enhance the generalisability of our findings for PA interventions that are substantially required in youth. Furthermore, given that PA interventions designed to improve youth participation and adherence have not been successful (Borde et al., 2017), our data could offer insightful knowledge that relates to the HIIE prescription (i.e. work intensities) and motivational perspectives that could impact the practicality of HIIE as a strategy to promoting health benefits in this cohort. The present study is limited as the HIIE protocol comprised cycling performed in a laboratory setting. Therefore, the findings may not apply to other exercise modalities (e.g. running) and limit the representations of a participant's real world affective response to exercise. Despite this limitation, the HIIE protocol adopted shows similar findings to recent work in adolescents examining affect responses during HIIE running (Malik et al., 2018a). Furthermore, a research design in a laboratory setting (e.g. lack of auditory, visual and social interaction) was required to ensure accurate comparison of perceptual responses (i.e. affect, enjoyment and RPE) and cardiorespiratory factors (i.e. HR and $\dot{V}O_2$) across all HIIE conditions. Another limitation concerns the reliability to assess all perceptual responses within the HIIE work and recovery intervals. However, the nature of the single-item scales permitted the collection of data with adequate temporal resolution during the exercise bouts. The participants were familiarised with the scales before undertaking the HIIE conditions. The method used in our study is consistent with previous work which has reported multiple items within similar time points during HIIE (Malik et al., 2018a; 2018b; Martinez et al., 2015).

Conclusion

In conclusion, our data comprehensively extends previous work on adolescents and indicates that some permutations of HIIE (i.e. 70% and 85% peak power) do not elicit prominent and entirely negative affective responses, as proposed by others (Biddle and Batterham, 2015; Hardcastle et al., 2014) and the DMT, which is based on continuous high intensity exercise and incremental exercise to exhaustion. HIIE performed at 100% peak power, however, fits the expected pattern of responses predicted by the DMT, which brings significantly greater declines and negative affective experiences across work intervals. Our data shows that HIIE evoked less pleasurable feelings towards the end work intervals compared to baseline regardless of intensity of the work intervals, but the affect experienced remained positive during 70%HIIE and 85%HIIE. Although data on the relationship between affective and enjoyment responses and long-term behavioural maintenance of exercise are not available in this study, it is plausible to suggest that performing 70%HIIE and 85%HIIE protocols could promote better exercise implementation and maintenance, considering the positive affect experienced when promoting such behaviour in youth. However, combined with the cardiorespiratory responses data, our findings show that incorporating a work intensity of 85% peak power for HIIE could potentially serve as suitable alternative HIIE prescription to be adopted for the promotion of health benefits in youth.

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Key points

- Affect responses during high-intensity interval exercise are dependent on work intensity.
- High-intensity interval exercise performed at 70% and 85% of peak power preserved positive affective responses (pleasurable feeling) but not at 100% of peak power.
- Similar enjoyment levels were evident during and after high-intensity interval exercise in all conditions.
- High-intensity interval exercise performed at 85% of peak power could serve as an optimal protocol when considering the impact of affect responses and the heart rate stimulus to facilitate exercise adherence and health promotion in youth.

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