Acute cardiorespiratory, perceptual and enjoyment responses to high-intensity interval exercise in adolescents

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Abstract

This study aimed to examine adolescents' acute cardiorespiratory and perceptual responses during high-intensity interval exercise (HIIE) and enjoyment responses following HIIE and work-matched continuous moderate-intensity exercise (CMIE). Fifty-four 12- to 15-year olds (27 boys) completed 8 x 1-min cycling at 90 % peak power with 75-s recovery (HIIE) and at 90 % of the gas exchange threshold (CMIE). Absolute oxygen uptake ($\dot{V}O_2$), percentage of maximal $\dot{V}O_2$ (%$\dot{V}O_{2max}$), heart rate (HR), percentage of maximal HR (%HR_{max}) and ratings of perceived exertion (RPE) were collected during HIIE. Enjoyment was measured using the physical activity enjoyment scale (PACES) following HIIE and CMIE. Boys elicited higher absolute $\dot{V}O_2$ during HIIE work (p<0.01, effect size (ES)>1.22) and recovery (p<0.02, ES>0.51) intervals but lower %$\dot{V}O_{2max}$ during HIIE recovery intervals compared to girls (p<0.01, ES>0.67). No sex differences in HR and %HR_{max} were evident during HIIE and 48 participants attained ≥90% HR_{max}. Boys produced higher RPE at intervals 6 (p=0.004, ES=1.00) and 8 (p=0.003, ES=1.00) during HIIE. PACES was higher after HIIE compared with CMIE (p=0.003, ES=0.58). Items from PACES 'I got something out of it', 'It's very exciting' and 'It gives me a strong feeling of success' were higher after HIIE (all p<0.01, ES>0.32). The items 'I feel bored' and 'It's not at all interesting' were higher after CMIE (all p<0.01, ES>0.46). HIIE elicits a maximal cardiorespiratory response in most adolescents. Greater enjoyment after HIIE was due to elevated feelings of reward, excitement and success and may serve as a strategy to promote health in youth.

Keywords: interval exercise, high-intensity, enjoyment level, exercise prescription, acute effect

Introduction

Observational studies in children and adolescents have demonstrated that cardiometabolic risk factors are more closely associated with vigorous intensity physical activity (PA) than light or moderate intensity PA (Ruiz et al., 2006; Steele, van Sluijs, Cassidy, Griffin, & Ekelund, 2009). Furthermore, recent studies have shown that only a small volume (<7 min) of vigorous intensity PA may be needed to promote health benefits in youth (Carson et al., 2014; Hay et al., 2012). Therefore, high-intensity interval exercise (HIIE) involving short repeated bouts of VPA, interspersed with periods of light recovery, has been adopted as a strategy for the promotion of health in adolescents. Recent reviews have shown HIIE training to be a feasible and time efficient method to improve cardiometabolic health and cardiorespiratory fitness in adolescents (Costigan, Eather, Plotnikoff, Taaffe, & Lubans, 2015; Logan, Harris, Duncan, & Schofield, 2014).

A commonly used HIIE protocol in the paediatric literature includes repetitions of 8-12 work intervals of 1 minute duration interspersed with 60–75 seconds of active recovery (Bond et al., 2015a; Cockcroft et al., 2015; Thackray, Barrett, & Tolfrey, 2016). Despite evidence for this HIIE protocol to promote a myriad of health benefits in adolescents, little is known about the acute cardiorespiratory [i.e., heart rate (HR) and oxygen uptake ($\dot{V}O_2$)] and perceptual [i.e., ratings of perceived exertion (RPE)] responses during HIIE in this population. These observations are because previous HIIE studies report the average cardiorespiratory and perceptual response to the entire HIIE protocol, which does not allow an in-depth quantification of the HIIE protocol to be provided, rather than by an interval by interval basis. Moreover, interval by interval quantification of the HR data can demonstrate participant compliance with the HIIE protocol using a predefined threshold in relation to percentage (%) HR maximum (Taylor, Weston, & Batterham, 2015). Therefore, as the intensity and duration of the work and recovery intervals during HIIE can influence the $\dot{V}O_2$, HR, RPE profile (Kilpatrick et al., 2015; Tschakert & Hofmann, 2013) and differ between males and females (Laurent, Vervaecke, Kutz, & Green, 2014) it is important that the acute cardiorespiratory and perceptual responses of boys and girls to HIIE are characterised and understood. Documenting this information will enable researchers, educators and coaches to safely, accurately, and effectively prescribe HIIE in paediatric populations.

The acute psychological responses to HIIE training has also garnered researchers' attention with some arguing that this form of exercise will generate negative affect and lack of enjoyment, thus leading to poor implementation and maintenance (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014). Paradoxically, enjoyment is reported to be higher after HIIE compared to continuous moderate intensity exercise (CMIE) in adolescents (Bond et al., 2015a; 2015b; 2015c). However, enjoyment following exercise was quantified using the modified physical activity enjoyment scale (PACES) by reporting as a total score across 16 items. In a recent debate on the application of HIIE to public health, Biddle and Batterham (2015) called for the reporting of individual PACES items to signify which items were responsible for the elevated enjoyment following HIIE. To the best of the author's knowledge, no study has documented the individual PACES items following HIIE compared to CMIE in adolescent boys and girls.

Therefore, the main purpose of the study was to describe the acute cardiorespiratory (HR and $\dot{V}O_2$) and perceptual (RPE) responses of adolescent boys and girls during an 8 x 1-min HIIE protocol. The secondary purpose was to evaluate the perceived enjoyment responses of adolescent boys and girls following HIIE compared to work-matched CMIE through analyses of the total and individual items of the PACES.

Methods

Participants

The data in the current study were obtained from previous work examining the health benefits of performing HIIE compared to work-matched CMIE (Bond et al., 2015a; 2015b; 2015c). For the current study, only data on the participant characteristics, acute cardiorespiratory, perceptual and enjoyment responses to HIIE and CMIE were used. An in-depth analysis of this data was not presented in previous published work. Relevant data were available on sixty participants although six participants (3 boys) were excluded due to missing gas exchange data. This resulted in a final sample of 54 12- to 15-yr-old adolescents (27 boys) for the current study. All participants volunteered to take part in the original studies and participant assent and parental consent were obtained. Ethics approval was granted by the Sport and Health Sciences ethics committee.

Anthropometric measures

Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg. 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 obese status were determined from Cole, Bellizzi, Flegal, and Dietz (2000). Body fat was estimated from skinfold thickness measures recorded at the triceps and subscapular to the nearest 0.2 mm using Harpenden callipers (Holtain Ltd, Crymych, UK). Pubertal status was determined by a self-assessment of secondary sexual characteristics using adapted drawings of the five Tanner stages of pubic hair development (Morris & Udry, 1980).

Cardiorespiratory fitness

Participants completed a combined ramp and supramaximal test to exhaustion on a cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) to establish $\dot{V}O_{2max}$ and the gas exchange threshold (GET) (Barker, Williams, Jones, & Armstrong, 2011).

HIIE and CMIE protocols

The HIIE protocol consisted of a 3 min warm-up at 20 W, followed by 8 × 1-min intervals at 90% of the peak power determined from the ramp test to exhaustion, interspersed with 75-s of recovery at 20 W, before a 2 min cool down at 20 W. The CMIE protocol incorporated continuous moderate-intensity cycling at 90 % of GET. The duration of CMIE was calculated to match the total external work performed during HIIE for each participant. Participants were encouraged to maintain a constant cadence between 70-85 rpm and remain seated in both HIIE and CMIE protocols. Participants were given verbal encouragement during both exercise protocols and information on how far during the test they had completed. Additionally, each participant was asked to identify which exercise bout they preferred after their final exercise trial.

Measures

Gas exchange and heart rate

Expired gas samples during the cardiorespiratory fitness test and exercise protocols (HIIE and CMIE) were measured on a breath by breath basis using a calibrated metabolic cart (Cortex Metalyzer III B, Leipzig, Germany). HR responses were recorded continuously using a telemetry system (Polar Electro, Kempele, Finland). Both gas exchange and HR data were subsequently averaged over 10-s time intervals. The GET was determined from the ramp test data and identified as the disproportionate increase in carbon dioxide production (VCO_2) relative to $\dot{V}O_2$. Maximal oxygen uptake ($\dot{V}O_{2max}$) was determined as the highest 10-s average in $\dot{V}O_2$ elicited either during the ramp or supramaximal test. Maximal HR (HR_{max}) was taken as the highest HR achieved during the ramp or supramaximal tests. A cut-off point of ≥90 % HR_{max} (Taylor et al., 2015) was used as the criterion for compliance to the HIIE protocol.

Rating of perceived exertion

Rating of perceived exertion (RPE) was assessed using the 1–10 Pictorial Children's Effort Rating Table (PCERT) (Yelling, Lamb, & Swaine, 2002). The PCERT has a range of numbers familiar to youth (1 to 10) and uses age appropriate verbal expressions as descriptors of exercise effort. The PCERT scale has verbal anchors from 'very, very easy' (1), 'very easy' (2), 'just feeling a strain' (4), 'hard' (7) up to 'so hard I am going to stop' (10). The same verbal instructions were given to all participants before undertaking the exercise protocols, and participants were given several minutes to familiarise themselves with the scale. RPE was determined at the end of the work intervals 2, 4, 6 and 8 during HIIE.

Perceived enjoyment

Perceived enjoyment after HIIE and CMIE was measured using the modified PACES for adolescents, which is validated for use with 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”). Total enjoyment was calculated by summing the 16 responses after seven items were reverse-scored. This yielded a possible range of scores from 16 through to 80 with a higher score representing greater enjoyment. In addition, individual item scores were also taken into account for the analysis. Participants completed the PACES within 5 minutes of finishing each exercise protocol

Statistical analyses

All statistical analyses were conducted using SPSS (SPSS 22.0; IBM Corporation, Armonk, NY, USA). The Shapiro-Wilks test was used to test the normality of the distributions. Descriptive characteristics (mean ± standard deviation) between boys and girls were analysed using independent samples t-tests. Cardiorespiratory, perceptual and enjoyment data were analysed using a two-way mixed model analysis of variance (ANOVA) with significance set at $p \leq 0.05$. In the event of significant effects, follow-up pairwise comparisons were conducted to examine the location of mean differences. Effect size (ES) was 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.

Results

The participants’ descriptive characteristics are presented in Table 1. Pubertal status of the boys and girls was as follows: Tanner stage 2, n = 3 and n = 0; Tanner stage

3, n = 9 and n = 7; Tanner stage 4, n = 10 and n = 17; Tanner stage 5, n = 4 and n = 4. Based on the international cut-offs for BMI, six participants (2 boys and 4 girls) were deemed overweight. A total of 22 boys and 21 girls (~ 81% of the sample) indicated that they preferred the HIIE exercise bout.

Cardiorespiratory and perceptual responses to HIIE

The mean interval by interval cardiorespiratory responses during the HIIE protocol are illustrated in Figure 1. A significant main effect was present for interval number (all $p<0.01$) for absolute HR and %HR_{max} responses during the work intervals. There were significant increases in HR across all consecutive work intervals (all $p<0.03$, ES>0.21), apart from work intervals 3 vs. 4 ($p=0.19$, ES=0.15) and 5 vs. 6 ($p=0.76$, ES=0.01). In boys, the average peak HR was achieved at the end of work interval 8 (187 ± 11 bpm) corresponding to 96 % HR_{max}. In girls, the average peak HR was also achieved at the end of the work interval 8 (185 ± 6 bpm) corresponding to 94 % HR_{max}. During HIIE, 48 participants (24 boys) reached the cut-off point of ≥90 % HR_{max} and typically occurred during HIIE work intervals 4 to 5.

There was a significant sex by interval number interaction ($p=0.02$) for absolute $\dot{V}O_2$ during the work interval of HIIE, but only a significant main effect ($p<0.01$) for interval number for %$\dot{V}O_{2max}$. Absolute $\dot{V}O_2$ was significantly higher in boys compared to girls for all work intervals (all *p*<0.01, ES>1.22). In boys, absolute VO_2 was significantly increased between work intervals 1 vs. 2 ($p<0.01$, ES=0.41) and 3 vs. 4 ($p<0.01$, ES=0.26). In girls, there were significant increases in VO_2 between work intervals 1 vs. 2 ($p<0.01$, ES=0.53) and 6 vs. 7 ($p=0.03$, ES=0.44). Boys attained their mean highest peak $\dot{V}O_2$ at the third work interval (2.25 ± 0.47 $L{\cdot}min^{-1}$) corresponding to 85 % $\dot{V}O_{2max}$. Conversely, in girls the mean highest $\dot{V}O_2$

was attained at the seventh work interval (1.79 ± 0.26 ± $L \cdot min^{-1}$) corresponding to 91 % $\dot{V}O_{2max}$.

There was a significant main effect for interval number (all $p<0.01$) in HR and $\%HR_{max}$ during the recovery intervals of HIIE. There were significant increases in HR across the recovery intervals (all $p<0.01$, ES>0.61), but not between intervals 5 vs. 6 ($p=0.22$, ES=0.09). In boys, the mean highest recovery HR was achieved during the seventh recovery interval (154 ± 10 bpm) corresponding to 79 % HR_{max}. In girls, the mean highest recovery HR was also achieved at the seventh recovery interval (159 ± 7 bpm) corresponding to 81 % HR_{max}. Significant effects for sex (all $p<0.02$) and interval number (all $p<0.01$), but not interaction (all $p>0.26$) were found in absolute $\dot{V}O_2$ and $\%\dot{V}O_{2max}$ during the HIIE recovery intervals. Boys elicited significantly higher absolute $\dot{V}O_2$ during recovery intervals (all $p<0.02$, ES>0.51), but significantly lower $\%\dot{V}O_{2max}$ compared to girls ($p<0.01$, ES>0.67). There were significant increases in $\dot{V}O_2$ during recovery intervals 4 vs 5 in boys ($p=0.03$, ES=0.40) and girls ($p=0.04$, ES=0.38).

Figure 2 presents the RPE data during the HIIE protocol. There was a significant sex by interval number interaction for RPE ($p=0.002$), with no difference between boys and girls at work intervals 2 ($p=0.25$, ES = 0.29) and 4 ($p=0.13$, ES=0.57). However, RPE was significantly higher in boys at work intervals 6 ($p=0.004$, ES=0.82) and 8 ($p=0.003$, ES=0.85).

Exercise enjoyment

There was a significant main effect for condition ($p=0.003$) with the PACES score higher after HIIE than CMIE in boys (HIIE=65 ± 8 vs. CMIE=58 ± 11, $p=0.003$, ES=0.73) and girls (HIIE=61 ± 6 vs. CMIE=58 ± 9, $p=0.02$, ES=0.39). Figure 3 illustrates the 16 single items PACES scores after HIIE and CMIE for boys and girls separately. For boys and girls, a higher score after HIIE compared to CMIE was found for items "I got something out of it" ($p<0.01$, ES=0.62), "It's very exciting" ($p<0.01$, ES=0.32) and "It gives me a strong feeling of success" ($p<0.01$, ES=1.58). Furthermore, boys and girls reported significantly higher scores after CMIE compared to HIIE for the items "I feel bored" ($p<0.01$, ES=1.26) and "It's not at all interesting" ($p<0.01$, ES=0.46).

Discussion

The primary findings from this study are: 1) boys elicited higher absolute $\dot{V}O_2$ responses during the work and recovery HIIE intervals, but elicited lower $\%\dot{V}O_{2max}$ during the HIIE recovery intervals compared to girls; 2) no significant differences between sexes were found for absolute HR and $\%HR_{max}$ during the work and recovery HIIE intervals and also for $\%\dot{V}O_{2max}$ during the work intervals; 3) 48 participants (89% of the sample) achieved ≥90 % HR_{max} during the HIIE protocol; 4) boys elicited greater RPE during the later stages of the HIIE protocol compared to girls; and 5) HIIE was perceived to be more enjoyable compared to CMIE for both sexes, with individual items on the PACES scale indicating elevated ratings of excitement, success and reward after HIIE.

In both sexes, the cut-off point of ≥90 % HR_{max} was attained following the fifth HIIE work interval and HR values drifted upward until HR reached 91-98 % HR_{max} during the final interval. Consequently, the ≥90 % HR_{max} threshold appears to be attained for approximately one third of the total work interval repetitions during HIIE. Few studies have documented the acute cardiorespiratory reponses during HIIE in youth, but our findings are consistent with the sparse literature. For example, Taylor et al. (2015) revealed that HR responses were typically lower (<90 % HR_{max}) following the first two intervals when compared to the rest of the work intervals in an HIIE session incorporating 4 x 45-s of maximal exercise with 90-s recovery. Recent studies by Thackray, Barrett, and Tolfrey (2013); (2016) also observed the highest HR was achieved (91-99 % HR_{max}) at the end of a 10 x 1-minute running HIIE protocol in recreationally active boys and girls. In contrast to HR, we observed that $\dot{V}O_2$ remained relatively fixed at ~ 80-85 % $\dot{V}O_{2max}$ after work interval 2 for the rest of the HIIE protocol and did not attain $\dot{V}O_{2max}$. This finding is in agreement with the work of Tucker, Sawyer, Jarrett, Bhammar, and Gaesser (2015) who also found significant increases in $\dot{V}O_2$ for first two work intervals without further increases during subsequent intervals of a 16 x 1-min HIIE protocol in men and women. However, much higher VO_2 responses (90–99 % $\dot{V}O_{2max}$) were found during a 4 x 4-min HIIE protocol when compared to the 16 x 1-min protocol (~76–85 % $\dot{V}O_{2max}$). We therefore reason that the use of 1-min duration work intervals for the HIIE protocol in the current study is likely to account for the close but not quite maximal $\dot{V}O_2$ responses in this present study.

In this present study we observed a 'stacking effect' in the HR, but not $\dot{V}O_2$, response during the HIIE work and recovery intervals (see Figure 1), suggesting the presence of the cardiovascular drift phenomena. This is consistent with an adult study showing an increase in HR but no change in $\dot{V}O_2$ during the recovery intervals of HIIE in male and female middle distance runners (Tocco et al., 2015). Interestingly, we also found that boys exhibited a lower %$\dot{V}O_{2max}$ compared to girls during recovery intervals which is similar to a study on adults employing a HIIE protocol incorporating 60 x 8-s intervals interspersed by 12-s of passive recovery

(Panissa et al., 2016). This sex difference may be explained by the higher aerobic fitness of boys since higher aerobic fitness is associated with a faster recovery of $\dot{V}O_2$ during the recovery intervals of HIIE (Panissa et al., 2014).

We observed an increase in RPE during the HIIE work intervals, which is consistent with previous HIIE studies in youth. For example, Thackray et al. (2013); (2016) revealed a progressive increase in RPE across the work intervals during 10 x 1-min running in adolescent boys and girls, respectively. However, although we found similar relative physiological responses between sexes when performing HIIE, boys had a higher RPE at the work intervals 6 and 8 compared to girls. In contrast to our data, a previous review revealed no differences in RPE between sexes during a graded exercise test or continuous exercise in youth (Groslambert & Mahon, 2006). An explanation for the current study's sex difference in RPE is not readily apparent but may be attributed to differences in the total amount of work performed during the HIIE protocol as boys were exercising at a greater power output during HIIE.

It is well documented that the motivation to participate in exercise or physical activity in youth is influenced by perceptions that the activity is fun and enjoyable or unpleasant and boring (Fox, 1991; Martens, 1996). In this present study, exercise enjoyment, as measured using the PACES, was higher after HIIE compared to CMIE that is consistent with previous findings (Bond et al., 2015a; 2015b; 2015c). A novel and original feature of the present study was the analysis of the individual PACES items, which found items "I got something out of it", "It's very exciting" and "It gave me a strong feeling of success", were significantly higher after HIIE compared to CMIE. In contrast, following the CMIE protocol, PACES items "I feel bored" and "It's not at all interesting" were significantly higher after CMIE compared to HIIE. It therefore appears that participants perceived a greater sense of reward, excitement, and success following HIIE compared CMIE. This could link to the attribution theory by Weiner (1986), which has been used to describe achievement-related behaviour. It has been proposed that individuals may attribute perceived success based on their high ability, hard work or challenge toward the task (Weiss, McAuley, Ebbeck, & Wiese, 1990). Baron and Downey (2007) also report that increasing youth's perception of success in different physical activity may also increase feelings of enjoyment. Given that enjoyment to physical activity in youth has been linked to the perceived success once they can succeed at experiences they find challenging (Martens, 1996), it could be suggested that the challenge posed by HIIE may be an important factor in increasing enjoyment levels compared to CMIE.

With regard to the participants' general perception of the exercise protocols, 81% of the participants expressed a preference for performing HIIE compared to CMIE. Coupled with the greater enjoyment following HIIE, our findings support the notion that exercise enjoyment could serve as a potential mediator for promoting youth PA as it may influence future exercise participation and non-participation (Allender, Cowburn, & Foster, 2006; Salmon, Brown, & Hume, 2009). According to the self-determination theory (Deci & Ryan, 1985), perceived enjoyment is an autonomous form of motivation, and this form of motivation is positively related to sustained health-promoting behaviours. Given that PA interventions designed to increase youth participation and adherence have not been successful (Borde, Smith, Sutherland, Nathan, & Lubans, 2017), HIIE could be an effective health improvement strategy in contrast to CMIE due to the elevated enjoyment and preference. In this present study, however, exercise enjoyment was measured post-exercise, and a recent debate on the application of HIIE as a public health strategy due to promote PA has questioned the role of HIIE due to elevated unpleasant feelings during the high-intensity exercise (Biddle & Batterham, 2015). Therefore, enjoyment responses during exercise alongside with affective (i.e. pleasure/displeasure feelings) evaluations are needed in future HIE studies on children and adolescents.

There are several limitations that should be acknowledged. This study documented the acute cardiorespiratory, perceptual and enjoyment responses to HIIE performed on a cycle ergometer and it is not possible to extrapolate to other exercise modalities (e.g. running) due to potential differences in cardiorespiratory responses (Millet, Vleck, & Bentley, 2009) and preference of exercise mode (Daley & Maynard, 2003). Another potential limitation is that enjoyment was quantified after, but not during, the exercise bouts.

Conclusion and practical applications

This study highlights the interval by interval basis of the cardiorespiratory responses during work and recovery phases of a commonly used HIIE protocol as well as the perceptual and enjoyment responses. Findings indicate that the 8 x 1-min HIIE protocol elicits a maximal cardiorespiratory response in the majority (~90%) of adolescents and is more enjoyable than CMIE due to elevated feelings of reward, excitement and success, which may have implications for using such protocols to promote health in youth. We recommend that the HIIE protocol should evoke ‘‘Just feeling a strain’’ (RPE 4–5) initially, and will be perceived as ‘‘hard or very hard’’ (RPE 7–8) by the end of the exercise with the associated HR response corresponding to ~162-168 bpm (~82-86 % HR_{max}) and ~183-189 bpm (~93-97 % HR_{max}).

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Conflict of interest

The authors declare the absence of any competing interest.

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Table 1 Descriptive characteristics of the participants

	Boys (n=27)	Girls (n=27)	p-value	ES
Age (y)	14.2 ± 0.6	14.1 ± 0.5	0.55	0.16
Body mass (kg)	57.7 ± 12.7	54.9 ± 8.7	0.36	0.26
Stature (m)	1.69 ± 0.10	1.62 ± 0.06	**<0.01**	**0.84**
BMI (kg/m^2)	19.8 ± 2.4	20.7 ± 2.6	0.25	0.36
Body fat (%)	15.2 ± 4.5	19.1 ± 6.6	**0.01**	**0.69**
HR_{max} (bpm)	194 ± 9	196 ± 5	0.20	0.27
$\dot{V}O_2$ (L·min^{-1})	2.71 ± 0.54	1.99 ± 0.27	**<0.01**	**1.67**
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	46.4 ± 5.7	35.9 ± 4.3	**<0.01**	**2.12**
GET (L·min^{-1})	1.34 ± 0.31	1.10 ± 0.16	**0.01**	**0.96**
GET (%$VO_{2\,max}$)	50.4 ± 6.5	55.8 ± 8.1	**<0.01**	**0.67**

Values are reported as mean ± standard deviation, probability (p), and effect size (ES). Significant differences are shown in bold. Abbreviations: $\dot{V}O_{2max}$, maximal oxygen uptake; HR_{max}, maximal heart rate; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; GET, gas exchange threshold.

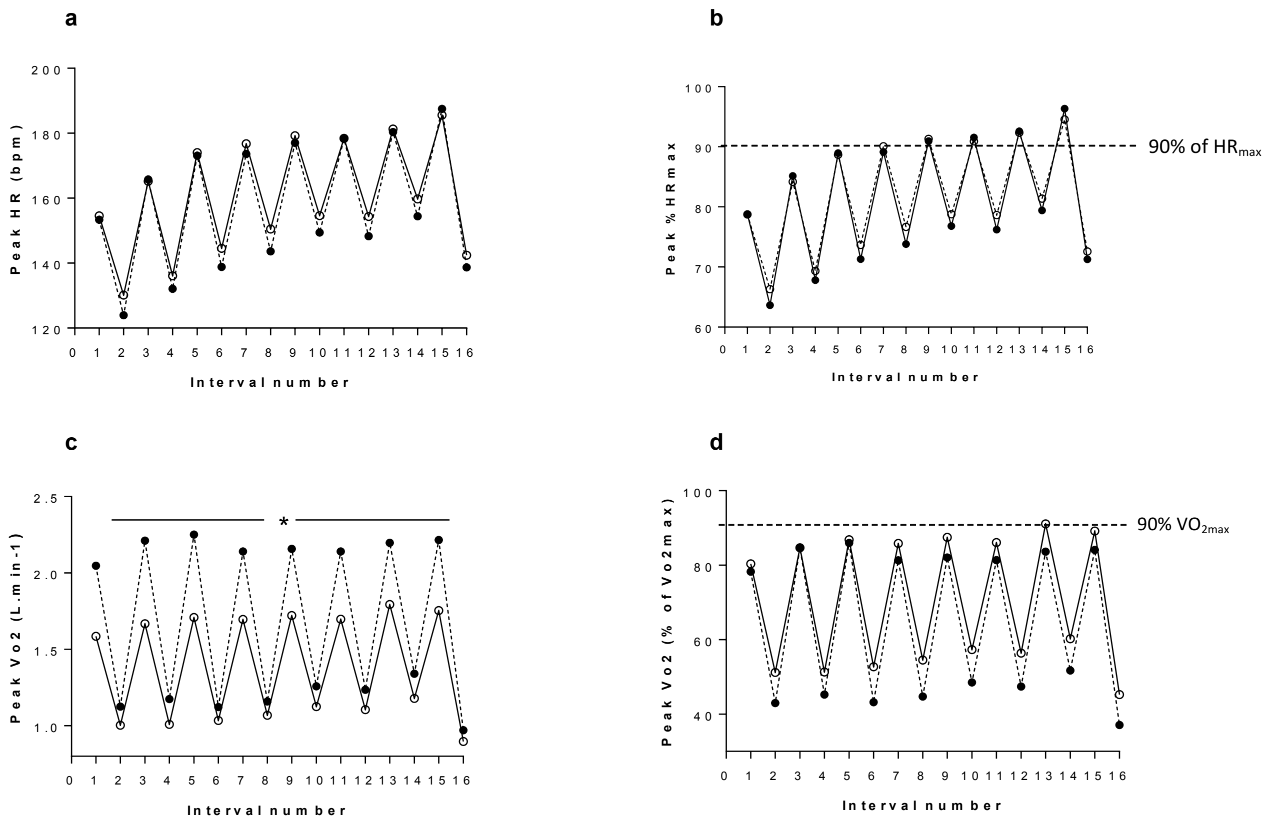


Figure 1. The mean peak heart rate (in beats per minute) (a), peak heart rate expressed as a percentage of maximal heart rate (b), peak oxygen uptake (in litres per minute) (c) and peak oxygen uptake expressed as a percentage of maximal oxygen uptake (d) during the interval and recovery phases of the HIIE protocol in boys (●) and girls (○). Where, the HIIE 'interval' phases are 1,3,5,7,9,11,13,15 and the HIIE 'recovery' phases are 2,4,6,8,10,12,14,16. *Significant sex by time interaction and main effects of sex. Error bars are omitted for clarity. See text for details.

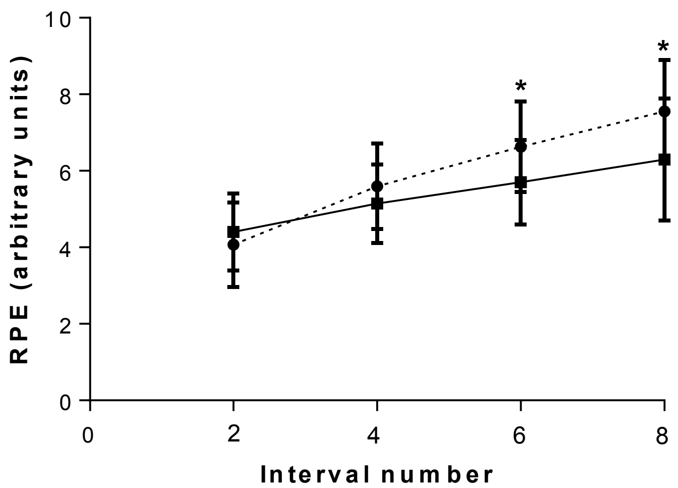
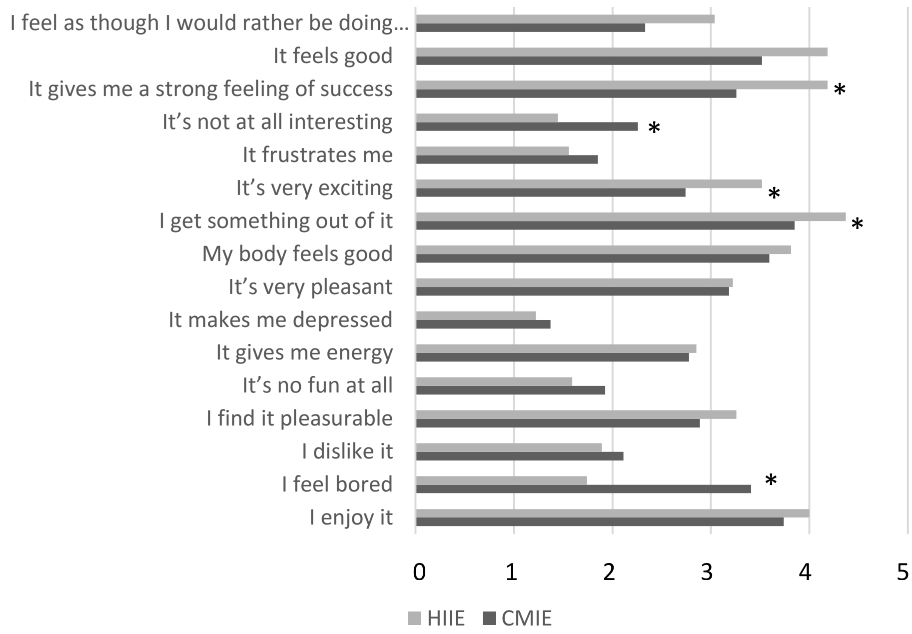


Figure 2. Mean and SD rating of perceived exertion (RPE) during 8x1-min high-intensity interval exercise (HIIE) with 75-s of recovery in boys (●) and girls (○).*Significantly different between boys and girls. See text for details.

a



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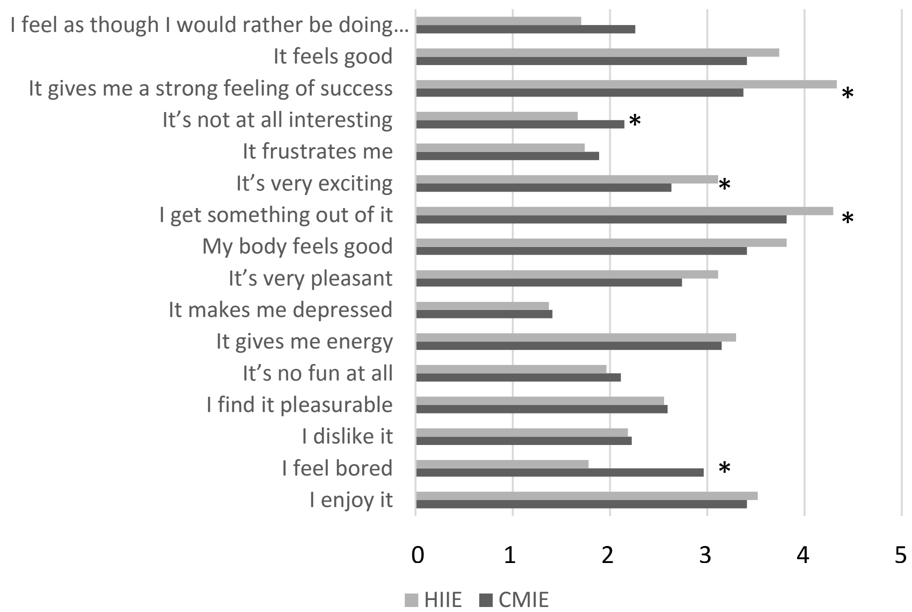

Figure 3. Mean (a) boys and (b) girls individual item score of the PACES following high-intensity interval exercise (HIIE; grey) and continuous moderate intensity exercise (CMIE; black). Item 1= "strongly disagree" to Item 5= "strongly agree". *Significantly different from CMIE protocol. See text for details.