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Perceptual and prefrontal cortex haemodynamic responses to high-intensity interval exercise with decreasing and increasing work-intensity in adolescents

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ABSTRACT

Objectives: Affect experienced during high-intensity interval exercise (HIIE) is dependent on work-intensity, but the influence of increasing (low-to-high (L-H)) or decreasing (high-to-low (H-L)) work-intensity during HIIE remains unclear in adolescents. The role of prefrontal cortex haemodynamics in mediating changes in affect during HIIE also remains unexplored in adolescents. We examined affect, enjoyment and cerebral haemodynamic responses to HIIE with increasing or decreasing work intensities in adolescents.
Methods: Participants (N = 16; 8 boys; age 12.5 ± 0.8 years) performed, on separate days, HIIE cycling consisting of 8 × 1-min work-intervals at 100%-to-70% ($HIIE_{H-L}$), 70%-to-100% ($HIIE_{L-H}$) or 85% ($HIIE_{CON}$) peak power separated by 75 s recovery. Affect, enjoyment and cerebral haemodynamics (oxygenation (ΔO_2Hb), deoxygenation (ΔHHb) and tissue oxygenation index (TOI)) were recorded before, during, and after all conditions. Results: Affect and enjoyment were lower during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ at work-intervals 1 to 3 (all $P < 0.043$, ES > 0.83) but were greater during $HIIE_{H-L}$ than $HIIE_{L-H}$ and $HIIE_{CON}$ at work-interval 8 (all $P < 0.048$, ES > 0.83). ΔO_2Hb was similar across conditions ($P = 0.87$) but TOI and ΔHHb were significantly greater and lower, respectively during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and $HIIE_{CON}$ at work-interval 8 (all $P < 0.039$, ES > 0.40). Affect was correlated with TOI (all $r > 0.92$) and ΔHHb (all $r > -0.73$) across conditions.
Conclusions: $HIIE_{H-L}$ offers advancement to the $HIIE_{CON}$ and $HIIE_{L-H}$ which bring significant greater affect and enjoyment towards the end HIIE work-interval, implicating the feasibility and adoption of this protocol for health promotion in youth. Also, changes in prefrontal cortex haemodynamics are associated with the affect during HIIE.

1. Introduction

High-intensity interval exercise (HIIE) has been shown to be a potent strategy to enhance cardiometabolic health and cardiorespiratory fitness in adolescents (Bond et al., 2017; Costigan et al., 2015). The adoption of HIIE to promote health benefits, however, has been disputed with some arguing that HIIE will generate negative affect (feelings of displeasure) and greater physiological (e.g. increased in heart rate (HR)) and exertional stress (e.g. increased rating of perceived exertion (RPE)), thus leading to poor implementation and maintenance in future sessions (Biddle and Batterham, 2015). Consequently, the effectiveness of HIIE protocol as a health strategy in youth is unclear.

The dual mode theory (DMT) provides a theoretical framework that integrates psychological/cognitive factors (e.g. self-efficacy) and physiological/interoceptive factors to explain the relationship between exercise intensity and affect responses (Ekkekakis et al., 2005). The DMT postulates that the dominant cognitive factor during exercise in the heavy exercise intensity domain (i.e. exercise performed above the ventilatory threshold (VT)) leads to large inter-individual variability, with some individuals perceiving the intensity as pleasurable, while others find it unpleasant (Rose and Parfitt, 2010). In contrast, physiological factors associated with metabolic strain (i.e. an increase in HR) dominate during exercise in the severe exercise intensity domain (exercise performed above the respiratory compensation point (RCP)).

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During the severe exercise intensity domain, the continuation of metabolic rate requires increased contributions of anaerobic sources and physiological steady state cannot be sustained, which leads to prominent feelings of displeasure (Ekkekakis et al., 2005). HIIE protocols are typically associated with a single work intensity that spans the heavy or severe exercise intensity domains (e.g. 70% to 100% of peak power, Bond et al., 2017). This reinforces the need to evaluate both psychological and physiological factors in research exploring HIIE as an effective health strategy in youth.

There are data in youth demonstrating that high-intensity exercise evokes prominent feelings of displeasure to support the DMT in youth. These observations were made during incremental exhaustive exercise and continuous exercise (Benjamin et al., 2012; Stych and Parfitt, 2011), which may not apply to HIIE involving brief bursts of high-intensity exercise separated by periods of low-intensity recovery exercise. Indeed, recent work has shown that pleasurable feelings are observed in 85% of participants during a commonly used HIIE protocol (i.e. 8×1 min performed at 90% peak power) in youth (Malik et al., 2018). The HIIE protocol also facilitated higher post-exercise enjoyment and preference compared to moderate-intensity continuous or interval exercise (Malik et al., 2017, 2018). The aforementioned studies are limited, however in terms of a single and constant work rate used to prescribe the HIIE protocol. Currently, no study has evaluated the effect of decreasing (high-to-low (H-L)) or increasing (low-to-high (L-H)) the work intensity during HIIE on the affective responses in adolescents. Zenko et al. (2016) recently reported that continuous exercise of H-L intensity resulted in more pleasurable feelings towards the end of an exercise bout when compared to L-H intensity. This report suggests that prescribing HIIE using H-L work intensities (e.g. decreasing from 100% to 70% peak power) could improve affect experienced during exercise. Elucidating this information is important, as HIIE protocols that are capable of attenuating unpleasant feelings during exercise could encourage future attitudes towards PA behaviour in adolescents (Schneider et al., 2009).

Previous research has shown HR and RPE to be elevated during HIIE and inversely correlated with the affective response in youth (Malik et al., 2018), suggesting that the decline in affect during HIIE may be related to the influence of physiological factors. The DMT predicts that the influence of physiological factors may hinder the ability of the prefrontal cortex (PFC) to control cognitive and affect processes, resulting in more negative affect (Ekkekakis and Acevedo, 2006). Reduced PFC activity occurs due to shifts in the metabolic resources (e.g. oxygen delivery) to the subcortical areas of the brain, driven by the intensified sensory body input (e.g. increased HR and RPE). It has been proposed that lower neural activation in the PFC is associated with a reduced (or plateau) cerebral oxygenation (ΔO_2Hb) in the presence of increased cerebral deoxygenation (ΔHHb) (Ekkekakis and Acevedo, 2006). Tempest et al. (2014) measured ΔO_2Hb in the PFC during an incremental test to exhaustion using near-infrared spectroscopy (NIRS), and found that changes in ΔO_2Hb were negatively correlated with changes in affect in healthy adult individuals. This observation suggests a potential mechanistic link between affect and the PFC during exercise. Whether the changes in affect evaluation during HIIE are related to PFC haemodynamics in youth, however, is currently unknown.

The purpose of this study is to examine the changes in affect, enjoyment and PFC haemodynamics (i.e. cerebral ΔO_2Hb, ΔHHb, and tissue oxygenation index (TOI)) in adolescents during H-L (100% to 70% of peak power; $HIIE_{H\text{-}L}$), L-H (70% to 100% of peak power; $HIIE_{L\text{-}H}$) and constant (85% peak power; $HIIE_{CON}$) HIIE work intervals. We hypothesised that $HIIE_{H\text{-}L}$ would elicit more positive affect (i.e. more pleasurable) and an elevated cerebral oxygenation towards the end of the exercise bout compared to $HIIE_{L\text{-}H}$ and $HIIE_{CON}$.

2. Methods

2.1. Participants

Sixteen adolescents (8 boys), aged 11 to 13 years old, volunteered to participate in the study. Prior to the recruitment, a brief explanation about this project was given to approximately 60 pupils during a school assembly. A total of 24 information packs (participant information sheet, health screening form, participant assent and parent consent forms) were taken by the pupils and sixteen were returned 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., 2018). Based on 3 (condition) by 8 (interval) repeated measures ANOVA with an alpha of 0.05 and power of 0.8, a sample size of 9 or 18 participants to detect a moderate and large effect was indicated, respectively. Exclusion criteria included the inability to understand the study procedures, musculoskeletal injury especially to lower limbs which prevents participants from cycling, the presence of any condition or infection which could alter mood and exercise performance. The study procedures were granted by the Sport and Health Sciences Ethics Committee (170712/B/02), University of Exeter. Written assent from the participants and written informed consent from the parent/guardian were obtained.

2.2. Experimental overview

This study required four laboratory sessions which took place in a satellite laboratory in the school, separated by a minimum two-day rest period (mean = 5, SD = 2 days), and incorporated a within-measures design. 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 different HIIE work-interval protocol, the order of which was counterbalanced to control for an order or learning effect. Each of the participants was assigned to perform the exercise test at the same time of the day between the hours of 08:30 to 13:00. All exercise tests and HIIE protocols were performed using an electronically braked cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands).

2.2.1. Anthropometric, maturation and physical activity measures

Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg using standard procedures. 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 (Cole et al., 2000)). Percentage body fat was estimated using triceps and subscapular skinfolds 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 maturers participants were defined as the offset score between -1 to 1 year and late maturers were defined as the offset score $> +1$ year.

Following completion of the HIIE protocols, participants wore an accelerometer (GENEActiv, GENEA, UK) on their non-dominant wrist for seven days. The accelerometer was set to record at 100 Hz. Participants' data were used if they had recorded ≥ 10 h/day of wear time for at least three week days and one weekend day (Riddoch et al., 2007). Data were analysed at 1 s epoch intervals to establish time spent in moderate and vigorous intensity physical activity using a cut-off point of ≥ 1140 counts per minute, which was previously validated in youth (Phillips et al., 2013).

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