Adolescents’ Perceptual and Physiological Responses to High-Intensity Interval Exercise

Submitted by Adam Bin Abdul Malik to the University of Exeter
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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

High-intensity interval exercise (HIIE) has been shown to promote multiple health benefits and well-being in youth. However, HIIE is proposed to elicit negative affect responses (unpleasant feelings) as predicted by the dual mode theory (DMT), and may negatively impact on future exercise adherence. Previous studies have explored how perceptual, physiological and cognitive factors are associated to negative affect responses during continuous high-intensity exercise, but affect experience (pleasure/displeasure) during HIIE is poorly understood in adolescents. The purpose of this thesis is to evaluate acute affect responses to HIIE in adolescents, and to examine the influence of physiological (i.e. heart rate (HR) and prefrontal cortex (PFC)), perceptual (i.e. enjoyment and rating of perceived exertion (RPE)), and cognitive (i.e. self-efficacy and personality traits) factors. Chapter 4 demonstrates that HIIE (work intervals performed at 90% of peak power (PPO)) is perceived to be more enjoyable due to elevated feelings of reward, excitement and success than continuous moderate-intensity exercise, which was perceived to be more boring in adolescents. Chapter 5 examined the acute affect, enjoyment and RPE responses to HIIE (work intervals performed at 90% of maximal aerobic speed) compared with moderate-intensity interval exercise (MIIE). Chapter 5 reports that HIIE elicits less pleasurable feelings at the later stages of work intervals but greater post-enjoyment than MIIE, extending and reinforcing the findings in Chapter 4. The findings from Chapter 5 are furthered in Chapters 6 and 7, which identified that the affect responses during HIIE are dependent on the intensity and delivery (decreasing vs increasing) of the HIIE protocol. Chapter 6 revealed that HIIE performed at 100% PPO elicited a greater decline and lower affect responses across all work intervals than HIIE performed at 85% and 70% PPO. However, all HIIE conditions generated

similar enjoyment responses during and after exercise. Chapter 7 showed that affect and enjoyment responses improve (more pleasurable and enjoyable) near the end of HIIE with decreasing work intensity compared to HIIE with increasing work intensity. Moreover, the increases in positive affect experienced during HIIE were positively related to an increase in PFC oxygenation. Chapters 5-7 also demonstrate that RPE and HR responses were inversely related to changes in the affect responses in all HIIE conditions. Finally, Chapter 8 identified that both individual self-efficacy and personality traits may decrease or increase the likelihood that a person will experience positive affective and enjoyment responses to HIIE at the later stages of work intervals in adolescents. Collectively, the studies presented in this thesis demonstrate that affect responses during HIIE are dependent on the work intensity, work delivery, and changes in enjoyment, RPE, PFC oxygenation and cognitive factors. Given that some permutations of HIIE protocols do not elicit prominent and entirely negative affective responses, HIIE protocols could serve as a strategy to encourage exercise adoption and promote health benefits in adolescents.

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Glossary of terms

AD ACL	Activation deactivation adjective check list
ANOVA	Analysis of variance
APHV	Age at peak height velocity
BAS	Behavioural activation system
BMI	Body mass index
bpm	Beat/min
BIS	Behavioural inhibition system
CALER	Cart and load effort rating scale
O_2Hb	Cerebral oxygenation
HHb	Cerebral deoxygenation
ΔFS	Change in the affect responses from work interval 1 to 8
ΔO_2Hb	Change in cerebral oxygenation from baseline to selected points
ΔHHb	Change in cerebral deoxygenation from baseline to selected points
CMIE	Continuous moderate-intensity exercise
CHIE	Continuous high-intensity interval exercise
DMT	Dual mode theory
EES	Exercise enjoyment scale
EFI	Exercise induced feeling
E-P scale	Eston-Parfitt curvilinear scale
ES	Effect size
FS	Feeling scale
FAS	Felt arousal scale
HIIE	High-intensity interval exercise
$HIIE_{H-L}$	High-intensity interval exercise performed form high to low peak power
$HIIE_{L-H}$	High-intensity interval exercise performed form low to high peak power
70%HIIE	High-intensity interval exercise performed at 70% peak power
85%HIIE	High-intensity interval exercise performed at 85% peak power
90%HIIE	High-intensity interval exercise performed at 90% peak power/maximal aerobic speed
100%HIIE	High-intensity interval exercise performed at 100% peak power
HR	Heart rate

HR_{max}	Maximal heart rate
$Km \cdot h^{-1}$	Kilometre per hour
$L \cdot min^{-1}$	Litre per minute
MAS	Maximal aerobic speed
$mL \cdot min^{-1} \cdot kg^{-1}$	Millilitre per min per kilogram
MIIE	Moderate-intensity interval exercise
MVPA	Moderate to vigorous intensity physical activity
NIRS	Near-infrared spectroscopy
PA	Physical activity
PACES	Physical activity enjoyment scale
%CV	Percent coefficient of variation
PFC	Prefrontal cortex
PHV	Peak height velocity
PPO	Peak power output
POMS	Profile of mood states
RPE	Rating of perceived exertion
Rpm	Revolutions per minute
S	Second
SEES	Subjective exercise experiences scale
SD	Standard deviation
SDT	Self-determination theory
SIT	Sprint interval training
SPSS	Statistical package for the social sciences
TOI	Tissue oxygenation index
VT	Ventilatory threshold
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}_E/\dot{V}CO_2$	Ventilatory equivalent for carbon dioxide
$\dot{V}_E/\dot{V}O_2$	Ventilatory equivalent for oxygen uptake
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen uptake
W	Watts
WHO	World health organisation

CHAPTER 1: Introduction

1.1 Physical activity in youth

Public health guidance recommends that children and adolescents (5-18 years of age) achieve at least 60 minutes of moderate to vigorous intensity physical activity (MVPA) every day, in addition to engaging in muscle and bone strengthening activities at least three times per week, to promote health and wellbeing (Department of Health, 2011, World Health Organisation (WHO), 2010). However, recent UK physical activity (PA) data reveals that only 16% of girls and 21% of boys aged 5 to 15 years achieve the levels of MVPA that are recommended and there is a steep decline in PA levels during adolescence in both genders (Townsend et al., 2015). The period of adolescence, therefore, appears to be a critical stage for the establishment of behavioural PA habits given behaviours accustomed during this period may continue into adulthood (Huotari et al., 2011).

Given evidence showing that few children and adolescents engage in the minimal requirement of PA, and the associated health risks of insufficient PA, it is important that interventions that encourage adoption and long-term adherence to PA are developed and evaluated. However, two recent meta-analyses incorporating objective measures of PA (i.e. accelerometers) reported a small effect of school-based interventions to augment PA in 6,153 children aged 1.8 to 13.1 years (Metcalf et al., 2012) and 11,515 adolescents aged 11 to 16 years (Borde et al., 2017). These studies may indicate that children and adolescents have difficulty in adhering to traditional PA programmes. Consequently, there is a strong rationale to study alternative forms of PA in youth, with one strategy focussing on smaller volumes of vigorous intensity PA.

Cross-sectional and longitudinal data collected from 9-17 year olds in Canada demonstrate that only a small volume (i.e. 7 and 4 minutes/day, respectively) of vigorous intensity PA may be needed to promote health benefits in youth (Carson et al., 2014, Hay et al., 2012). Importantly, data are available to show that time spent performing moderate intensity PA was not associated with health benefits (e.g. adiposity and cardiorespiratory fitness) in youth (Ruiz et al., 2006, Steele et al., 2009, Barker et al., 2018), suggesting it is the vigorous component of the current MVPA guideline that drives the health benefits. These data reinforce the idea that interventions consisting of small daily doses of vigorous intensity PA (i.e. quality not quantity) may be a useful strategy regarding health promotion, especially in adolescents given that PA levels are known to decline from childhood (Townsend et al., 2015). Furthermore, small doses of vigorous intensity PA has been adopted in PA guidelines for adults (18–64 years of age) as at least 150 minutes per week of moderate PA are recommended, but this falls to 75 minutes per week for vigorous intensity PA (WHO, 2010).

1.2 High-intensity interval exercise

Researchers have commonly utilised exercise as a form of activity to improve PA levels while promoting health benefits in children and adolescents (Costigan et al., 2015, Logan et al., 2014). Exercise is a subset of PA that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective (Caspersen et al., 1985). One form of exercise that may be used to deliver short bouts of vigorous intensity PA for the promotion of health in adolescents is high-intensity interval exercise (HIIE). The application of HIIE protocols is intriguing in youth as their PA is characterised by spontaneous and intermittent behaviour rather than continuous PA (Bailey et al., 1995, Armstrong et al., 1990). Barkley et al. (2009) have also shown that interval exercise, regardless of intensity (i.e. moderate- and high-intensity), is more reinforcing than continuous constant intensity exercise in children. The reinforcing value of an activity can be thought of as an individual's motivation to participate in that activity and may reflect motivational processes that can increase the possibility of engaging in a particular behaviour (Epstein and Roemmich, 2001). Therefore, HIIE may provide an attractive form of exercise in youth as the protocol mimics their typical PA behaviour. Furthermore, a growing body of literature indicates that HIIE is perceived to be more enjoyable than a bout of continuous moderate-intensity exercise (CMIE) in youth (Bond et al., 2015a, 2015b, 2015c). Finally, the Physical Activity Guidelines Advisory Committee (2018) called for the evaluation of novel forms of exercise for population-level health promotion in USA, of which HIIE is highlighted.

HIIE typically involves alternating periods of high-intensity exercise with low-intensity recovery intervals. Although the fundamental concepts of HIIE are linked to sports training for endurance athletes (Billat, 2001), such protocols have recently been designed and adapted for both general and clinical populations (Gibala et al., 2012, Bond et al., 2017). HIIE protocols can be created, by manipulating intensity, duration, and work-to-recovery ratios within sessions (Buchheit and Laursen, 2013). Given these variables, the numbers of protocols available is infinite and the delivery of HIIE can be in the form of traditional (e.g. running and cycling) or novel (e.g. invasion game-based exercise) forms of exercise (Valantine et al., 2017). Although a variety of HIIE protocols have emerged in the paediatric literature, they are primarily based on three different models that vary in terms of intensity, duration and total exercise duration (Table 1.1).

Table 1.1 Models of high-intensity interval exercise from the paediatric literature

Model	Work repetitions	Work intensity	Work duration (s)	Total work duration (minutes)	Total exercise commitment (minutes)
SIT	4-6	Maximal sprint effort	<30	2 - 3	~ 20
Low-volume	8-10	90% of maximal effort achieved during an incremental test to exhaustion	60	8 - 10	20-25
Scandinavian	4	90%<HR_{max}	240	16	~ 28

SIT, sprint interval training; s, second; HR_{max}, maximal heart rate

A traditional HIIE model is based on repeated Wingate-style exercise intervals and is better known as sprint interval training (SIT). SIT typically consists of 4 - 6 repeated bouts of ‘all-out’ 30 s exercise, performed on a cycle ergometer, separated by recovery periods of 4 minutes of unloaded pedalling. This provides a total of ~ 120 to 180 s of high-intensity effort in an exercise session, lasting about 20 minutes in duration (Gibala et al., 2006). Previous studies with youth have also utilised other variations of SIT, characterised by very short work durations of SIT (≤ 10 s) separated by recovery intervals (Sedgwick et al., 2015, Baquet et al., 2001). However, as the repeated bouts of SIT require maximal effort, concerns related to the tolerability and acceptability of this form of exercise have been raised (Coyle, 2005).

In an attempt to remain relatively time efficient but also to expand the application of low-volume HIIE to a wider spectrum of users, a less intense and more practical model of HIIE was developed by reducing the work intensity and increasing the duration and number of work intervals (Little et al., 2011). This recent and more practical protocol has shifted towards prescribing the work interval intensity based on maximal performance achieved during an incremental test to exhaustion (e.g. % of peak power output (PPO) for cycling or % of maximal aerobic speed (MAS) for running) rather than power output elicited during an 'all out' sprint (Little et al., 2011). A commonly used version of this practical HIIE model in the paediatric literature includes 8 - 10 repeated bouts of work intervals performed at 90% PPO/MAS determined from a prior incremental test to exhaustion, interspersed with active recovery intervals of 60 - 75 s duration (Bond et al., 2015a, Thackray et al., 2016, Cockcroft et al., 2015). This protocol is considered ''low-volume'' HIIE because the total time spent performing high-intensity exercise is <10 minutes and the total exercise commitment is typically between 20 to 25 minutes.

Another HIIE protocol adopted in paediatric studies incorporates 4 repeated bouts of 4 minutes intervals, separated by a recovery of 3 - 4 minutes of duration (Tjonna et al., 2009, Ingul et al., 2010). This HIIE model is known as the 'Scandinavian Model' and was initially developed for clinical populations (e.g. cardiac patients or people who are obese). This HIIE model is performed below the HR_{max} (e.g. at 90% of HR_{max}) and is therefore less intense than SIT. However, this protocol is considered ''high-volume'' HIIE because the total time spent performing high-intensity exercise is

~ 16 minutes and the total exercise commitment is typically ~ 28 minutes, meaning the total time commitment is similar to traditional endurance training approaches.

Recent investigations have suggested that HIIE, regardless of the protocol used, produces equal if not superior health benefits at considerably lower volumes of total work, when compared with continuous exercise at a lower intensity (Costigan et al., 2015, Logan et al., 2014, Bond et al., 2017). The multiple health benefits of HIIE in youth has recently been compiled in published reviews (Costigan et al., 2015, Logan et al., 2014, Bond et al., 2017), showing that HIIE protocols are effective at improving cardiometabolic health markers (e.g. body composition, blood lipids, glucose and insulin) and augmenting cardiorespiratory fitness in adolescents. These review papers therefore support HIIE as a potentially efficacious form of exercise for the improvement of health outcomes in adolescents.

1.3 Issues concerning the adoption of high-intensity interval exercise

Apart from the health benefits of HIIE, a growing body of evidence supports greater enjoyment after HIIE, and is a more preferable type of exercise compared to CMIE in youth (Bond et al., 2015a, 2015b, 2015c). However, a contemporary debate regarding the effectiveness of HIIE as a public health strategy has raised concerns that it will not be adopted or maintained by many people (Biddle and Batterham, 2015, Hardcastle et al., 2014). Specifically, Biddle and others have argued that the intense work intervals performed during HIIE may evoke negative affect responses (feelings of displeasure) and a greater perception of exertion, which may lead to poor implementation and adherence (Biddle and Batterham, 2015, Hardcastle et al., 2014). This contention is based on the dual-mode theory (DMT; Ekkekakis et al., 2005b), which explains the relationship between affective responses (pleasure/displeasure) and exercise intensity. Elucidating affective responses during exercise is important as affective evaluation during exercise may predict future attitudes towards PA behaviour in adolescents (Rhodes and Kates, 2015).

Several studies in youth have showed that exercise performed above the ventilatory threshold (VT, a non-invasive estimation of the lactate threshold), termed as high-intensity, during incremental and continuous type protocols has an affective response that is prominently negative in support of the DMT (Benjamin et al., 2012, Stych and Parfitt, 2011, Sheppard and Parfitt, 2008b). Nevertheless, these evaluations were conducted using continuous or incremental exercise models, which may not translate to a HIIE protocols as it involves brief bursts of high-intensity exercise separated by periods of low-intensity recovery exercise. Moreover, previous HIIE studies have shown that low- or moderate-intensity exercise performed during the HIIE recovery intervals may not hold prominent negative feelings and high exertional stress (i.e. perceived exertion), when the high-intensity exercise is performed in brief bursts interspersed with periods of recovery in adults (Jung et al., 2014, Martinez et al., 2015, Niven et al., 2018). Indeed, Batterham has argued that with the countless permutations of intervals possible, it is conceivable that pleasurable feelings during HIIE exist to address the feasibility of the application of HIIE as a public health strategy (Biddle and Batterham, 2015). Whether HIIE is perceived as aversive by youth populations however, is currently unknown.

An advantage of HIIE is that many exercise regimes can be prescribed by manipulating the intensity and duration of the work and recovery intervals (Buchheit and Laursen, 2013). Given that exercise intensity plays a significant role in the regulation of affect responses during exercise, as proposed by DMT (Ekkekakis et al., 2005b), there is potential to explore the different work interval intensities of HIIE to improve affective responses (maintain pleasurable feelings). Furthermore, previous research has indicated that affective responses are modulated not only by exercise intensity per se but also by the cardiorespiratory (e.g. heart rate (HR)) and perceived exertion responses (Oliveira et al., 2015). It therefore appears that evaluating the physiological and perceived exertion during HIIE is vital as the intensity of the work intervals during HIIE can influence the oxygen uptake ($\dot{V}O_2$), HR, rating of perceived exertion (RPE) profile (Kilpatrick et al., 2015b, Tschakert and Hofmann, 2013).

Evidence has also indicated that individual cognitive factors such as self-efficacy and personality characteristics may increase or decrease the likelihood that a person will experience feelings of pleasure/displeasure during high-intensity exercise (Schneider and Graham, 2009, McAuley and Courneya, 1992), but these have yet to be explored in the context of HIIE in youth. Finally, the DMT predicts that the influence of physiological factors (e.g. increased in HR) may impede the function of the prefrontal cortex (PFC) to control individual cognitive factors and affect processes during high-intensity exercise, resulting in more negative affect (Ekkekakis and Acevedo, 2006). Currently, only one study in adults has evaluated cerebral oxygenation in the PFC during an incremental test to exhaustion using near-infrared spectroscopy (NIRS) (Tempest et al., 2014). Whether the changes in affect evaluation during HIIE are related to PFC haemodynamics in youth, however, is currently unknown.

1.4 Thesis rationale

PA is important for health promotion but the majority of adolescents do not achieve the recommended levels of PA. As traditional PA interventions designed to increase PA in youth have been largely unsuccessful, there is a need to develop alternative strategies to engage adolescents in sufficient PA to maintain and improve their health and well-being. Low-volume HIIE has emerged as a potent exercise strategy to improve health benefits in youth, yet the adoption and maintenance of this protocol is unclear. The novel aim of this programme of work is to optimise the prescription and implementation of HIIE protocols by evaluating affective responses to HIIE in adolescents, and to examine the influence of physiological (e.g. HR and PFC), perceptual (e.g. enjoyment and RPE) and cognitive (e.g. self-efficacy and personality traits) factors. Consequently, this thesis will evaluate the applicability of the DMT framework to HIIE in adolescents and build on current knowledge concerning the area of affect and exercise with adolescents. Prior to detailing the experimental work conducted throughout this thesis, Chapter 2 will provide a critical review of the related literature and Chapter 3 will provide an overview of the methods and procedures used. Collectively, these chapters will present a rationale and the intended aims and methodological approaches of the experimental work undertaken (Chapters 4-8).

CHAPTER 2: Literature review

2.1 Introduction

The purpose of this chapter is to critically examine a conceptual model of affective response to exercise intensity, which incorporates the DMT. This literature review will initially presents a brief limitation of the dominant theory associated with health behaviour research in youth. This will be followed by a discussion on conceptual and methodological research on affective responses, as well as an explanation of the application of the DMT to exercise. Studies adopting both continuous and incremental exercise in children and adolescents will be presented. Next, key adult studies related to affect responses during HIIE will be highlighted that have contributed to the major themes examined in this thesis. This will be followed by a review on the effect of HIIE on the physiological, enjoyment, and perceived exertion responses in youth, as well as a discussion on the relations of these factors to the affect responses. Finally, the objectives and hypotheses of each study that will be examined in this thesis will be presented.

2.2 Theoretical models of physical activity behaviour

Studies associated with PA behaviour in youth often focus on cognitive factors, consistent with the prevailing socio-cognitive theoretical models such as the transtheoretical (Prochaska and Velicer, 1997), health belief (Becker, 1974), and the theory of planned behaviour (Ajzen, 1991) models. Researchers have adopted these models in order to predict, explain, and alter PA behaviour with the goal to overcome the problem of physical inactivity in youth (Plotnikoff et al., 2013). These models centre on the fundamental assumption that individuals are future-oriented;

systematically collect and analyse pertinent and available information; rationally weigh pros and cons to their main goal; and make reliable predictions about the future consequences that commonly compliment with their own self-interest (e.g., perceived health benefits) (Borde et al., 2017). However, outcomes of PA or exercise interventions that have been developed based on these assumptions to improve youth participation and adherence have consistently only explained modest correlations in PA behaviour and are scarcely successful (Plotnikoff et al., 2013, Borde et al., 2017, van Sluijs et al., 2007). For example, a recent meta-analysis by Plotnikoff and colleagues (2013) of 23 studies (4,073 boys and girls aged 12–18 years) found that socio-cognitive theories, on average, explained between 24% and 35% of PA behaviour. Consequently, with up to two-thirds of exercise behaviour unexplained, socio-cognitive theories alone do not describe a complete picture of PA behaviour in adolescents. Moreover, a recent systematic review and meta-analysis of 13 studies (11,515 boys and girls aged 11 to 16 years) reported that PA interventions based on these assumptions (e.g. health education workshops and school nurse-delivered counselling sessions including body weight and information of body weight management) do not elicit meaningful improvements in total PA (standardised mean difference = 0.02) and MVPA (standardised mean difference = 0.24) in youth (Borde et al., 2017). These studies reinforce the need for reconsideration of the fundamental assumptions that underpin PA promotion interventions in youth. One of the most unexplored or understudied factors underlying PA behaviour in youth is the subjective experiences that people derive from their participation during PA.

2.3 Affect responses

The subjective experience of exercise is complex and multidimensional, and often involves mutiple factors, such as, cognitive reactions, emotion, feelings (e.g. liking, enjoy) and thoughts (Hoffman and Knudson, 2018). However, one factor that has been identified as having potential motivational significance in behavioural change is the affective response that exercisers experience (Ekkekakis, 2003). Affect is a generic term that characterises the evaluation of a subjective experience of the basic component of all valenced states (e.g., pleasant or unpleasant, positive or negative), including, but not limited to, the concepts of emotion and mood (Ekkekakis et al., 2005b). Ekkekakis and Petruzzello (2000) have suggested that the affective domain, referring to affect, emotion and mood, can be conceptualised as having a hierarchical structure, which extends from a basic affect (Russell, 2009), to distinct emotions that are generated following specific patterns of cognitive appraisals. Russell (2003) further established the concepts of affect as a neurophysiological state that is consciously accessible through the combination of hedonic (feelings of pleasure or displeasure) and activation (arousal). It has been theorised that affect is the simplest and broadest concept in the affective domain (Ekkekakis and Petruzzello, 2000).

In contrast to affect, the concept of emotion requires a cognitive appraisal of a specific stimulus, and is typically characterised as being of relatively short duration and high intensity (e.g., feeling of pride and joy) (Ekkekakis and Petruzzello, 2002, Ekkekakis, 2003). However, affect may appear as one of the components of an emotion (e.g. pride is pleasurable), or in the absence of a cognitive appraisal (e.g., feelings of displeasure associated with pain). Finally, the concept of mood is theorised as involving a cognitive origin, and tends to be less intense and longer lasting than emotion; mood is seen as lacking a specific target (e.g., might involve depression and irritability) (Ekkekakis and Petruzzello, 2002, Ekkekakis, 2003).

2.3.1 Role of affect response to facilitate exercise adherence

Research shows that optimising affect responses (e.g. an increase in pleasant feelings) during exercise may be one solution to improving PA levels, as affect may be the first link in the exercise adherence chain (Schneider et al., 2009, Williams, 2008). A critical aspect that may play a role in people's adherence (or not) to PA involves how the exercise makes them feel (referring to their affect), while they engage in it. This viewpoint is embedded in 'hedonic theory' which postulates that people tend to be attracted to pleasant stimuli and avoid unpleasant stimuli, indicating that behaviour has a direct relationship with its affective consequences (Cabanac, 1971). Kahneman (2003) proposed that the perceived usefulness of a behaviour or experience is defined by one's affective response to the behaviour, and will determine whether the behaviour will be repeated in the future. A positive affect response (i.e. feelings of pleasure) as opposed to negative affect response (i.e. feelings of displeasure) has an impact upon an individual's motivation and behaviour (Parfitt et al., 2006), which may influence any decisions made, regarding whether or not to re-engage in the behaviour in the future (Williams et al., 2008, Kiviniemi et al., 2007).

A recent systematic review of 24 studies by Rhodes and Kates (2015) was conducted to evaluate whether the affective response to exercise relates to future PA behaviour. The authors reported that positive affect responses (based on average, peak and end point of affect) during exercise (effect size (ES) ranged from r=0.51-0.18) related to future PA behaviour (based on four studies with total of 434 participants, aged 14 - 65 years), but no significant relationship (r=0.21) between affect responses following the exercise bout with future PA were evident (based on nine studies with total of 755 participants, aged 14 - 65 years). Out of four studies that examined the influence of affect responses during exercise, only one included adolescents. In this cross-sectional study, Schneider et al. (2009a) examined the change in affective valence during continuous high-intensity exercise (CHIE; PPO between VT and $\dot{V}O_{2max}$) and CMIE (PPO at 80 % of VT) and its relationship to seven day accelerometer MVPA measured before completion of the cycling exercise in 124 adolescents (aged 14 - 16 years old). The authors reported that participants who elicited an improvement (indicated as a positive affect), no change (indicated as a neutral affect) and decline (indicated as a negative affect) in affective valence from baseline to the mean of affect responses at 10 and 20 minutes during CMIE engaged in an average of 54, 46 and 39 daily minutes of MVPA, respectively. This finding indicates that participants who have a more positive affect during CMIE engaged in more MVPA as compared to neutral and negative affect experienced. Additionally, after controlling for aerobic fitness and gender, a 1-unit increase in the Feeling scale (FS; single-item scale used to measured affect responses) measurement of affect predicted 4 minutes of additional daily MVPA. However, Schneider et al. (2009a) revealed that affective responses during CHIE were not associated with MVPA (note: no regression analyses values were included), suggesting that CHIE may not facilitate MVPA participation. The findings observed by Schneider et al. (2009a) are consistent with the other three studies in adults (Williams et al., 2008, Kwan and Bryan, 2010, Williams et al., 2012), showing that CMIE was correlated with the amount of PA undertaken in the follow-up 3-6 months (r= 0.18-0.51 across studies) in men and women (aged between 18-48 years old).

However, the affective responses during CHIE were not considered in these three studies on adults.

It is plausible to suggest that the dissociation between CHIE and total MVPA observed by Schneider et al. (2009a) is partly due to the decline in affect responses and negative affect valence (indicated by negative score of FS) near the end of exercise bout in 85% of the participants. Although 56% of the participants experienced a decline in affective valence in CMIE, they reported primarily positive affect responses (indicated by the positive score of FS) near the end of exercise bout. This may suggest that both the magnitude of changes in affect during exercise and affect at the end of exercise bout are warranted to provide dynamic affect evaluation to exercise. Indeed, research has shown that the positive affective experience and subsequent decisions about PA behaviour are derived from the peak affective experience and the final experiences while engaged in the exercise behaviour (Hargreaves and Stych, 2013, Parfitt and Hughes, 2009). These observations were initially reported in the social study by Fredrickson and Kahneman (1993). They examined the retrospection global evaluation (e.g. how much pleasure, displeasure or discomfort did you experience?) of affect experiences immediately after watching aversive (e.g. man being forcibly drowned) and pleasant (e.g. puppy playing with flower) film clips that varied in duration in 32 adults (aged 16-35 years). The author suggested three features of the affective experience that are most consequential, namely, the affective peak (positive or negative), the rate of decline or incline of affect during the episode, and the affect at the end of episode. Indeed, Fredrickson (2000) highlighted two moments during the episodes that contained the most intensely experienced affect (i.e. peak affect), and the one that concluded the experience (i.e. end affect) guiding people's choices about which past experiences they would repeat, and which they would avoid.

Hargreaves and Stych (2013) examined the peak-end affect experienced in the context of exercise with 41 inactive women (aged 42.7 ± 10.6 years). The participants completed 20 minutes of continuous constant-speed treadmill exercise, at an intensity either at the VT or 10% above the VT, while affect responses were recorded every 2 minutes during-exercise and 1, 5, 10 and 15 minutes, 2 and 7 days post-exercise. The authors reported that peak affect (defined as the most positive or least negative FS score) and end affect (FS value recorded at the end of the 20 minutes bout of exercise) explained between 39 and 58% of the variance in global affective evaluation (i.e. measured of remembered utility of the pleasantness or unpleasantness of the exercise experience) from 5 minutes to 7 days post-exercise. This study reinforces the notion that the peak and end affective evaluation during exercise predicted the affective memory of an exercise experience. In regards to the slopes (decline or incline) of affect during exercise, Zenko and colleagues (2016) reported that an increase in positive affect responses during 15 minutes of continuous cycling exercise accounted for 35–46% of the variance in remembered and forecasted pleasure from 15 minutes to seven days post exercise in 46 adults (aged 18-40 years old).

The aforementioned studies, therefore, show that the peak, end and slopes of affect experienced during exercise provide strong evaluative memories that facilitate the amount of time people will subsequently choose to spend in that situation when it comes to future exercise behaviour (Rhodes and Kates, 2015, Hargreaves and Stych, 2013, Parfitt and Hughes, 2009). Consequently, formulating the temporal change of affect during exercise involving peak, end and incline/decline of affect responses is warranted as it is linked to future exercise adherence (Williams, 2008, Rhodes and Kates, 2015, Schneider et al., 2009).

2.3.2 Measuring affect: categorical/distinct vs. dimension/broad states

As alluded above, evaluating the affect responses during exercise may be pertinent regarding future exercise adherence. Therefore, researchers need to identify methodological approaches that are compatible in measuring affect responses not only before and after exercise, but also during exercise. An important consideration when choosing a measure to assess the affective domain is whether the goal is to assess a specific (narrowly defined state) or broad dimensions that are theorised to underpin a global domain such as core affect (Ekkekakis and Petruzzello, 2000). This decision is mainly because the specific or broad dimensions approaches have significant implications to the selection of the measurement tools (e.g. single-item vs. multiple-item) and it being bound to a specific affective domain (e.g. mood, emotion and affect) (Ekkekakis and Petruzzello, 2000).

Previously, researchers often generalised the ‘feel better’ effect that individuals gained from exercise based on the distinct states or categorical approach rather than the broad/dimensional approach (Ekkekakis and Petruzzello, 1999). The categorical approach implies that affective states are organised according to specific categories that potentially offer the unique features of the psychological meanings (e.g. emotions and moods). However, the categorical approach taps into states of specific feelings such as depression, tension, confusion, anger, fatigue, vigour, or anxiety, which are measured using a specific inventory such as the Profile of Mood States (POMS; McNair et al., 1971), Exercise-induced Feelings Inventory (EFI; Gauvin and

Rejeski, 1993) and Subjective Exercise Experiences Scale (SEES; McAuley and Courneya, 1994). Consequently, the categorical approach could limit fully representative or the broader dimensions of the affective states that originate from the stimulus properties of exercise (e.g. exercise intensity). This reinforces the need to evaluate the affective valence, pleasure/displeasure, which represents the broadest concept of affective states when examining the affective experience associated with exercise (Ekkekakis and Petruzzello, 2000).

Williams (2008) indicated that the dimensional approach is pertinent to assess the affective responses associated with exercise rather than a categorical approach, citing two critical reasons. The author argued that a dimensional approach can theoretically provide the representation of a full range of affective responses by relying on a small set of dimensions that in turn reflect the similarities and differences among affective states (Ekkekakis and Petruzzello, 2002). Indeed, the affective states are related to each other in a highly systematic fashion, but not independent of one another (Russell, 1980). Secondly, a dimensional approach commonly involves a single item assessment that is compatible for evaluating temporal changes of affect before, during, and after exercise (Ekkekakis and Petruzzello, 2002). This is contrary to the categorical approach that tends to involve multiple-item assessments which limits the measurement of affective states to before and after the exercise (e.g. POMS; EFI, and SEES). Indeed, a systematic review by Ekkekakis and Petruzzello (1999) of 31 studies indicated that the measurement of the acute affect before and after seems to be problematic due to the potential of nonlinear changes, or dynamic changes, of affect during the exercise session.

Attempting to improve the methodological platform for examining the affective responses during exercise , Ekkekakis and Petruzzello (1999) proposed the use of a dimensional approach using the circumplex model of affect (Russell, 1980). The circumplex model (Figure 2.1) represents a conceptual framework for measuring affect responses along with bipolar and two orthogonal, unrelated, dimensions known as valence (displeasure/pleasure) and activation (low/high of arousal) (Ekkekakis and Petruzzello, 2002). The two underlying orthogonal dimension of valence and activation of the circumplex model have been shown to account for most of the variance (95%) in the inter-correlations among ratings on 28 affect terms (Russell, 1980). Russell (1980) indicated that the systematic interrelationship of affective dimensions could be represented by a spatial model (see Figure 2.1). Specifically, this model is divided into quadrants, each characteristic of different meaningful variants of affective states. These states are: 1) the unactivated/pleasant, characteristic of calmness and relaxation; 2) the unactivated/unpleasant, characteristic of boredom, depression, or fatigue); 3) the activated/unpleasant, characteristic of tension or nervousness; and 4) the activated/pleasant, characteristic of excitement, energy or happiness.

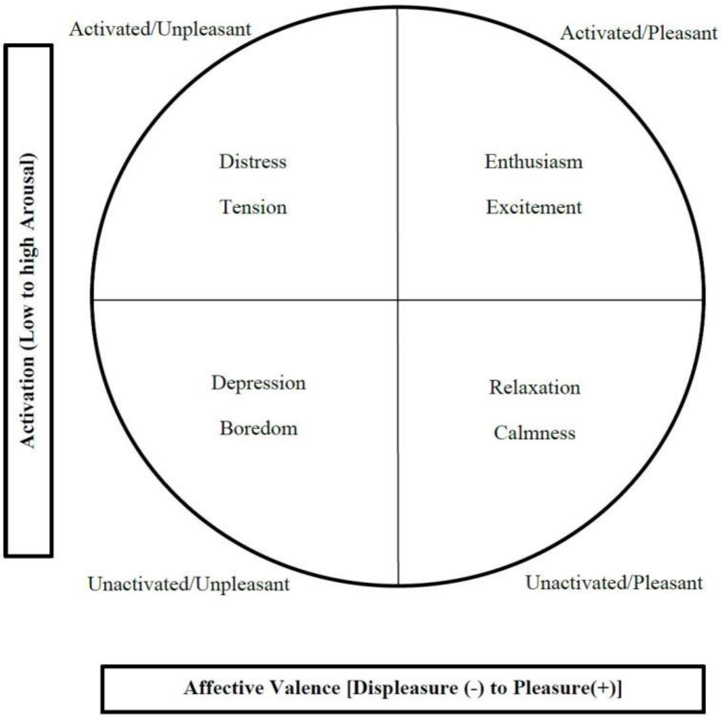

Figure 2.1 A graphical representation of the circumplex model of affect with the *horizontal axis* representing the affective valence dimension and the *vertical axis* representing the arousal or activation dimension. The valence dimension describes the degree to which an emotion is pleasant or unpleasant, and the arousal dimension describes the degree to which an emotion is associated with high or low energy (Russell, 1980).

The propencey of the circumplex model to differentiate changes in activation that may be independent of changes in affective valence, render this model as a suitable option for the study of affective responses in the context of exercise. Indeed, failure to differentiate the changes between the valence and activation dimensions may lead to misleading outcomes (Ekkekakis and Petruzzello, 2002), a problem that has been shown to be especially pronounced in studies that utilized unidimensional measures of state anxiety such as the State-Trait Anxiety Inventory (Spielberger et al., 1970). Furthermore, this model could capture all major variants of affect that are likely to occur in different individuals' under different exercise conditions across the range of exercise intensities using only two elemental dimensions (Ekkekakis and Petruzzello, 2002). Despite all its advantages, the analysis of the circumplex model to examine the affect responses to exercise has not been fully explored in youth.

There are a number of single-item instruments for measuring affective responses in a circumplex model of affect (e.g. self-assessment manikin (Lang, 1980) and affect grid (Russell et al., 1989)), but researchers have extensively used the FS and the felt arousal scale (FAS) when evaluating affect responses during exercise (Rhodes et al., 2015). Furthermore, it has been noted that the unconventional format of the self-assessment manikin (cartoon strips) and affect grid (a grid) may confuse some participants compared to the more familiar ratings format (i.e. numbering and verbal anchors format) of the FS and FAS (Ekkekakis and Petruzzello, 2002). The FS scale was developed to capture the core of affect, pleasure/displeasure, whereas the FAS was developed to capture perceived activation, low/high arousal. The development of these single-item scales has enabled researchers to examine time-by-time affective valence during an exercise task while minimising the burden on the participants during exercise, especially when involving youth. Although these two scales were not developed originally for the affect circumflex structure and there is a possibility of erroneous responses (i.e. due to confusion or carelessness) (Russell, 1980), the advantage of these tools in comparison to the multi-item measures is that they can repeatedly measure affect responses during exercise in order to evaluate the temporal changes that may occur during exercise. Moreover, the possibility of erroneous responses of FS and FAS should be minimised via a familiarisation session and clear explanations of the scale before undertaking exercise. Therefore, the ability to allow the collection of affect responses data with adequate temporal resolution during the exercise bouts identifies the FS and FAS as an essential and pertinent method to be adopted.

As highlighted previously, limiting the measurement of affect responses to the periods before and after exercise, and precluding the assessment of affect responses during exercise, would result in a failure to discriminate the pathway leading to post-exercise outcomes (Reed and Ones, 2006, Ekkekakis and Petruzzello, 1999). Consequently, the adoption of the dimension approach and single-item measurement is warranted because affect responses during exercise play as potential determinant of future exercise adherence compared to before and after exercise (Rhodes and Kates, 2015). This is mainly because these methodological considerations allow the comprehensive evaluation of affect responses during exercise as suggested by Ekkekakis and Petruzzello (2002). However, it is important to highlight that the link between exercise adherence and affect responses during exercise are related to the intensity of the exercise itself (Rhodes and Kates, 2015). Indeed, a systematic review of 33 studies by Ekkekakis et al. (2011) revealed that exercise performed at a moderate and high intensity elicited either pleasurable or unpleasant feelings during exercise, respectively. Therefore, it is pertinent to consider whether a certain level of exercise intensity would be likely to cause increases or decreases in pleasure to promote future exercise behaviour. Given that the intensity of exercise, specifically via HIIE, appears to be an important consideration regarding health promotion in adolescents (see Chapter 1), the influence of exercise intensity on affective responses is a critical issue that needs to be examined in the paediatric literature and will be discussed in the next section.

2.4 Affective responses and exercise intensity

2.4.1 The inverted-U model

The traditional assumption concerning the dose-response relationship between the intensity of exercise and affect is an inverted-U model (Figure 2.2). This model assumed that moderate intensity (not 'very low' and not 'very high') maximises the conditions for positive affective experiences during exercise. In contrast, low intensity PA is insufficient to generate any significant affect change from baseline and high intensity PA is experienced as aversive or negative affect (Kirkcaldy and Shephard, 1990, Ojanen, 1994, Ekkekakis et al., 2005b). Consequently, it has been proposed that people should engage in moderate intensity PA to experience positive affective change.

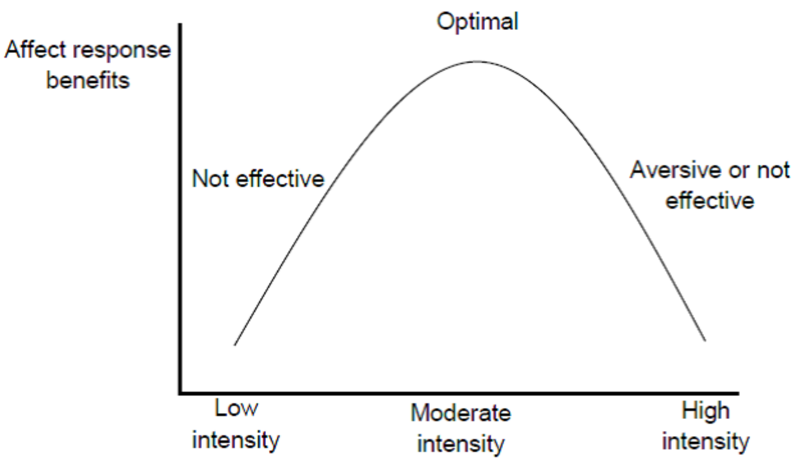

Figure 2.2 The inverted-U model with the x *axis* representing the exercise intensity and the y *axis* representing the benefits of affect experience. An intensity that is ‘‘very low’’ is proposed to be insufficient in eliciting affective benefits. By contrast, exercise at an intensity that is ‘‘very high’’ may be ineffective or aversive. An intensity that is not ‘‘very low’’ and not ‘‘very high’’ (moderate intensity) is proposed to elicit the optimal stimulus for positive affective benefits. Adapted from Ekkekakis et al. (2005b).

Ekkekakis et al. (2005b) argued that the inverted-U model is based on a descriptive model and does not yield any testable hypotheses or theory that could explain the underlying causes of the observed affective evaluations. Consequently, the mechanistic explanation for the changes of affect responses to different exercise intensity based on the inverted-U model is unclear. Furthermore, the assumption of this model is not consistent with the extant literature as it fails to consider for inter-individual variation in affect responses during exercise, as highlighted in a systematic review of 31 studies (Ekkekakis and Petruzzello, 1999). For example, Van Landuyt et al. (2000) evaluated whether CMIE (30 minutes of cycling at 60% of $\dot{V}O_{2max}$) generated primarily positive affect responses across a sample of 83 participants, aged 19.9 ± 1.4 years. The authors indicated that 44% of participants reported a gradual improvement, whereas 26% of participants reported a gradual decline, in FS score from baseline, indicating large inter-individual variation during moderate-intensity exercise. Using data based on continuous exercise and incremental exercise to exhaustion, Ekkekakis (2003) developed the DMT which outlines the dose-response relationship between affective responses to exercise intensity with individual variation.

2.4.2 Dual mode theory

The relationship between exercise intensity and affective responses can be explained via the conceptual framework known as the DMT (Ekkekakis, 2003). The DMT posits that there are two factors underlying the affective responses during exercise: 1) cognitive cues that reflect psychological factors, such as self-efficacy, goal achievements, attributions and an individual’s personality; and 2) interoceptive cues that reflect physiological strain, related to changes in HR, breathing rate and body temperature. Cognitive cues originate primarily in the prefrontal cortex, while the interoceptive cues come from a variety of receptors such as chemoreceptors, which are stimulated by exercise-induced physiological changes. The DMT proposes that the dual influence of these two factors serves to alter the affective evaluation and shifts systematically, as a function of exercise intensity domains (moderate, heavy or severe (Gaesser & Poole, 1996)), and will be explained below and are summarised in Table 2.1 (Ekkekakis et al., 2005b).

Table 2.1 Affective responses by exercise intensity

Exercise intensity domain	Affect responses	Cognitive factor	Physiological factor
Moderate	Homogeneity in positive affective responses (pleasure)	Low to moderate influence	Low influence
Heavy	Variability in affective responses (pleasure or displeasure)	Strong influence	Moderate to strong influence
Severe	Homogeneity in negative affective responses (displeasure)	Low influence	Strong influence

This evidence is taken from Ekkekakis et al. (2005b).

2.4.2.1 Moderate exercise intensity domain

The DMT predicts that in the moderate exercise intensity domain (exercise intensity below the VT), there is low-to-moderate influence of cognitive processes (e.g. self-efficacy and personality traits), with interoceptive cues associated with the physiological strain of exercise having minimal influence (Ekkekakis et al., 2005b).

During the moderate exercise intensity domain, exercise can be sustained for prolonged periods of time as aerobic sources to supply the energy are sufficient and a physiological steady state can be maintained, or is not threatened (Hall et al., 2002). Consequently, the affect responses during this type of exercise are postulated to be positive and homogenous between individuals.

2.4.2.2 Heavy exercise intensity domain

As the exercise intensity increases from the VT to the respiratory compensation point (RCP), termed the heavy exercise intensity domain, cognitive processes are suggested to have greater influence on the resulting affective responses. However, during this exercise intensity domain, the contribution of interoceptive cues becomes apparent with many metabolic strain or bodily cues (e.g. increased HR and ventilation) entering the individual's consciousness, although they will only have a small impact. Within this intensity range, exercise can be sustained for relatively prolonged periods, but with higher associated metabolic strain than for moderate-intensity exercise. An additional slow component is developed after some minutes of exercise at this intensity (Xu and Rhodes, 1999). This slow component causes oxygen uptake to increase progressively and delays the attainment of the steady-state level. The occurrence of the slow component is closely associated with metabolic strain and exercise intolerance (Poole et al., 1994). Consequently, affective responses are expected to exhibit marked inter-individual variability, such that some individuals may perceive the exercise as pleasurable, while others as unpleasant. This marked inter-individuality of affect responses is mainly due to the different individual cognitive factors (e.g. self-efficacy and personality traits) to tolerate with these bodily cues which are discussed in section 2.5.

2.4.2.3 Severe exercise intensity domain

Within the severe exercise intensity domain, increased contributions from anaerobic sources are required and a physiological steady state can no longer be maintained. Specifically, physiological variables associated with metabolic strain, including HR, $\dot{V}O_2$, and blood lactate, exhibit a continuous 'slow component' which leads to the termination of exercise at or close to the participant's maximal aerobic capacity (i.e. $\dot{V}O_{2max}$) (Xu and Rhodes, 1999). The severe exercise intensity domain is associated with declining levels of pleasurable feelings or positive affective responses. Previous studies have consistently shown that during severe intensity exercise, the negative correlations between affect valence (measured by FS) and various indices of metabolic strain (HR, ventilation, respiratory rate, blood lactate and $\dot{V}O_2$) increased in magnitude compared to the moderate-intensity exercise (Acevedo et al., 1994, Hardy and Rejeski, 1989). The affective responses are proposed to be uniformly less positive, or unpleasant, with minimal inter-individual variability, because the physiological cues signal physical harm, implying that the individual should stop exercising (Ekkekakis, 2003). Hall et al. (2002) propose that affective responses in the severe domain represent an evolutionary primitive 'alarming' function, which, much like pain, is aimed to stop the individual and have them withdraw from the activity that is causing severe disruptions to their homeostasis.

2.4.2.4 Affective contrast phenomenon

The DMT also predicts that the instantaneous improvement in affect responses from displeasure to pleasure, also known as affective contrast phenomenon or opponent process theory, occurs immediately after heavy or severe intensity exercise (aversive stimuli). According to Solomon (1991) this is because of the adaptation benefits associated with the removal or termination of an unpleasant stimulus during aversive stimuli and the return to affective equilibrium (Ekkekakis et al., 2005b). Solomon (1991) proposed that affective responses are the algebraic sum of two processes, namely, A- and B-processes that reflect the negative affect and positive affective valence, respectively. It has been proposed that A-process closely tracks the intensity of the generating stimulus especially during high-intensity exercise and dissipates immediately after the termination of the stimulus. In contrast, B-process which is characterised by a slower build-up and decay, increases with repeated exposures to the stimulus during exercise and continues to incline even after the termination of stimulus. This results in the greater influence of B-process in comparison to A-process after the exercise. Therefore, the opponent process theory could potentially explain the improvement of affect experienced from unpleasant feelings elicited during high-intensity exercise, to more pleasurable feelings following the exercise.

2.4.3 Acute affective responses to exercise in youth

The majority of the aforementioned evidence on affect responses during exercise is based on adult studies, but a number of paediatric based studies are published and are summarised in Table 2.2. Studies have examined the acute affective responses to exercise during an incremental exercise test to exhaustion, or during continuous exercise at varying exercise intensities, and broadly support the DMT. For example, Sheppard and colleagues (2008b) investigated the relationships between exercise intensity and affective responses during incremental exercise to exhaustion in sedentary men (aged 35.5 ± 7.2 years) and boys (aged 12.5 ± 0.5 years). They reported that affective valence (measured using FS) significantly declined in both groups after the VT to the end of the incremental exercise (ES for men= 2.59 to 5.31; ES for boy= 1.0 to 2.67), supporting the DMT. However, men’s affective responses significantly declined from the second minute to the point of the VT (ES= 0.66 to 0.72); a pattern not observed in the boys' affective responses (ES= 0.18 to 0.54). Following this initial investigation, Benjamin et al., (2012) examined the intensity-affect relationship during incremental exercise to exhaustion in children (aged 8–11.8 years) and adolescents (age 11.9–14 years). Data from this study supports a uniform decline in affect above the VT, as per the findings by Sheppard et al. (2008b), but indicate that the decrease in affect responses was significantly greater in adolescents (ES=1.63) compared to children (ES=0.41) when exercise was performed above the VT to the end of incremental exercise. The authors (Benjamin et al., 2012) also reported that FS scores were lower at the end of the incremental exercise to exhaustion in the adolescent group (-2.17 ± 0.5) compared to children (-1.31 ± 0.6). Collectively, these studies revealed that exercise at an intensity above the VT brings about a significant decline in affective valence in youth, with scores below zero on FS (e.g., <-1.7) observed at the end of incremental exercise to exhaustion. Therefore, findings indicate that this protocol generated feelings of displeasure toward the end of exercise bout, which was more pronounced in adolescents than children.

Studies have also examined the pattern of affective change during acute bouts of continuous exercise at varied intensities relative to the VT. Using a similar protocol, Sheppard et al. (2008a) and Stych and Parfitt (2011) examined the affect responses during continuous cycling exercise consisting of 15 minutes at 130% of PPO at VT, 80% of PPO at VT and 100% of PPO at VT in 22 high active adolescents (aged 13.3 ± 0.33 years) and 16 low active adolescents (aged 12.5 ± 0.5 years). These authors reported that exercise performed at intensities relative to the individual VT confirm the DMT, showing a significantly less positive and greater decline in affect responses during exercise performed above the VT (e.g. FS score at 5 to 15 minutes= 1.8 to -0.5) compared to exercise performed below the VT (e.g. FS score at 5 to 15 minutes= 2.8 to 2.4) and at the VT (e.g. FS score at 5 to 15 minutes= 0.8 to 0.7) (Stych and Parfitt, 2011, Sheppard and Parfitt, 2008a). Both studies reveal that during exercise prescribed at an intensity beyond the VT (e.g. heavy or severe exercise, but collectively termed as high-intensity exercise), the affective responses will rapidly decline and become mostly negative (feelings of displeasure) in adolescents.

Another important observation found in the existing paediatric literature to support the DMT is the inter-individual variability in affect responses. Stych and Parfitt (2011) reported considerable variability in affect responses at and above the VT (heavy to severe domain), with some individuals interpreting the intensity as pleasurable (38% of participants), while others as unpleasant (58%). Based on qualitative data, the authors highlighted the major factors that contributed to the changes in affect evaluation during heavy and severe exercise. These factors included participants' perception of confidence that they could complete the test, the perception of challenge towards the exercise intensity, and the interpretation of the negative physiological cues during exercise. With regard to the physiological cues, participants consistently described uncomfortable physical sensations of aches and pains in the muscles, feeling hot, sweating, and having shortness of breath and a pounding heart. However, it is currently unknown whether affective responses to exercise are related to changes in physiological strain (e.g. HR responses) and individual cognitive factors (e.g. self-efficacy and personality traits) in youth. Elucidating this information is important as the relationship between cognitive/physiological factors and affective evaluation during exercise may vary between exercise intensity (see details discussion in section 2.5 and 2.6, respectively). This reinforces the needs to focus on individual cognitive and physiological factors alongside exercise intensity when examining affect responses to exercise in youth.

Out of four studies highlighted above, only two studies have include the circumplex model of affect to illustrate the dynamical changes of affect and perceived activation during exercise, and are limited to incremental exercise to exhaustion (Benjamin et al., 2012, Sheppard and Parfitt, 2008b). Sheppard and colleagues (2008b) revealed that for the adolescents boys (aged 12.5 ± 0.5 years), affective responses moved from the inactivated pleasant domain, via the pleasant activated domain, into the activated unpleasant domain the second minute after VT using the circumplex model. This pattern concurs with Benjamin and colleagues (2011) with young adolescent boys and girls (aged 11.9–14 years). Collectively, these studies revealed that incremental exercise to exhaustion generates feeling of tension or nervousness in adolescents as reflected by the activated unpleasant quadrant. Additionally, both studies reported that as exercise progressed from the heavy to the severe exercise intensity domain, there was a continued increase in perceived activation, accompanied by a progressive decline in affective valence. This observation may suggest that perceived activation could influence the overall exercise intensity perception of affect evaluation. The available evidence reinforces the need to evaluate the dynamically changes of affect evaluation to different exercise intensity using the circumplex model, as recommended by Ekkekakis and Petruzzello (1999).

Despite an emerging body of evidence in support of the DMT for studies including children and adolescents, there has been minimal research exploring the affective responses to HIIE in this age group. Specifically, there is clear evidence that adolescents who engage in CHIE, such as exercise above the VT, experience prominent unpleasant feelings as indicated by a negative FS, and a significantly greater decline of affect responses compared to low or moderate-intensity exercise. However, this evidence cannot be extrapolated to HIIE, as HIIE involves alternating work and recovery intervals that consist of high and low intensity exercise respectively, which would be expected to alter the intensity-affect relationship in youth. Thus, this area of research is in its infancy and more work needs to be conducted to identify whether a negative affective response is present during HIIE in adolescent populations.

Table 2.2 Studies evaluating the relationship between affect responses and exercise intensity in youth

Study	No. of subjects, sex, and age	Design and factors	Exercise mode	Exercise protocol	Measures and administration time points	Findings
Sheppard and Parfitt (2008a)	22 adolescents (11 male and 11 female; aged 13.3 ± 0.33 years)	Within-subject	Cycle ergometer	Cycling at a self-selected intensity, low intensity (80% of PPO at VT) and high intensity (130% of PPO at VT) for 15 minutes.	FS; 5 minutes pre, immediately before the start, last 45 sec. of each 5 minutes period during, 5, 10, 15, 30 minutes post.	Affect responses significantly declined and became less positive during high-intensity over low or self-selected intensity across exercise bouts. High-intensity exercise elicited negative affect responses at the end of exercise.
Sheppard and Parfitt (2008b)	13 men (35.3 ± 12.1 years) and 10 boys (aged 12.5 ± 0.5 years)	Within-subject	Cycle ergometer	Incremental exercise (increased by 40 W for men but 20 W for boys every 2 minutes) to exhaustion.	FS, FAS, CALER scale; last 20 sec. at the end of every incremental step	FS showed significant decline and negative affect responses above the VT in both groups.

Continued overleaf

Table 2.2 (Continued)

Study	No. of subjects, sex, and age	Design and factors	Exercise mode	Exercise protocol	Measures and administration time points	Findings
Schneider, Dunn & Cooper (2009a)	124 adolescents (57 male, 67 female; aged 14.8 ± 0.5 years)	Within-subject	Cycle ergometer	Cycling at moderate intensity (80% of the PPO at VT) and high intensity (PPO at 50% of the differences between VT and VO_{2max}) for 30 minutes	FS; at 0,10, 20, 30 minutes during, 10 minutes post	High-intensity exercise elicited greater decline in affect responses compared to moderate-intensity exercise. Positive affect responses during exercise below the VT were associated with greater participation in the MVPA but not during high intensity.
Stych & Parfitt (2011)	12 boys, 14 girl; aged 12.5 ± 0.5 years	Within-subject	Cycle ergometer	Cycling at self-selected intensity, low intensity (80% of PPO at VT) and high intensity (130% of PPO at VT) for 15 minutes.	FS; 5 minutes pre, immediately before the start, last 45 s of each 5 minutes period during, 5, 10, 15, 30 minutes post.	Affect responses significantly declined and became less positive during high-intensity over low or self-selected intensity across exercise bouts. The displeasure feelings during high-intensity exercise was attributed to the negative physiological cues, levels of confidence, and sense of achievement

Continued overleaf

Table 2.2 (Continued)

Study	No. of subjects, sex, and age	Design and factors	Exercise mode	Exercise protocol	Measures and administration time points	Findings
Benjamin, Rowlands & Parfitt (2012)	49 children- 23 children and 26 adolescents (21 male and 28 female); aged 8-14 years	Within-subject	Treadmill	Incremental exercise (the gradient was increased by 1% per minute at self-selected speed) to exhaustion	FS, FAS, E-P scale; last 20 s at the end of every incremental step.	Incremental exercise 1 minute after the VT elicited greater decline in affect responses in adolescents compared to children. Both groups generated negative affect responses at the end of incremental exercise.

AD ACL= Activation Deactivation Adjective Check List; FS= Feeling Scale; FAS= Felt arousal scale; CALER scale= Cart and Load Effort Rating scale; E-P scale= Eston-Parfitt curvilinear ratings of perceived exertion; VT= ventilatory threshold; PPO= peak power output

2.4.4 Acute affective responses to high-intensity interval exercise

While HIIE may represent a promising strategy for increasing vigorous intensity PA and improving health outcomes, as highlighted in the Introduction (see Chapter 1), the DMT has been extended to propose that HIIE will be perceived as aversive, and thus it would be unlikely that people would pursue this type of exercise (Biddle and Batterham, 2015, Hardcastle et al., 2014). This suggests poor implementation and adoption of HIIE as a way to improve health and well-being at the population level. Consequently, the relevance of HIIE may be questionable from a public health perspective. However, HIIE typically involves bouts of high-intensity exercise above the VT which can span the heavy to severe exercise intensity domains interspersed with recovery periods of low-intensity exercise. Hence, low-intensity exercise performed during recovery may not be associated with negative affect when high-intensity exercise is performed in brief bursts interspersed with periods of low-intensity recovery. These recovery periods provide not only relief after exercising at an intense level, but may also result in participants having a sense of gratification due to the experience of a rebound affective response (Solomon, 1991, Bixby et al., 2001). Indeed, low-intensity exercise performed during HIIE recovery intervals could potentially elicit pleasurable feelings after an aversive stimulus generated during the HIIE work intervals, as proposed by Bixby et al. (2001). Thus, it may be proposed that there are several opportunities for this potential rebound in affect during a HIIE recovery interval, which may alter the dose response relationship between affect responses and exercise intensity during HIIE in contrast to CHIE.

Available data demonstrates the exercise intensity-affect relationship during HIIE, but the evidence is mainly limited to adult-based studies. However, a single study has evaluated affect responses to two different HIIE protocols that corresponded to performing 5 or 10 x 1 minutes work intervals at 100% of MAS interspersed with 1 minute recovery in adolescent girls (aged 12.1 ± 0.7 years) (Thackray et al., 2016). They reported a significant decline in affective responses measured using FS across the HIIE work intervals in both protocols (3 ± 2 to -2 ± 3, ES= 2.99 for HIIE with 10 repetitions; 3 ± 2 to -1 ± 2, ES=1.57 for HIIE with 5 repetitions). Although both protocols reported unpleasant feelings at the end of HIIE work intervals, the authors argued that the similar high enjoyment levels (indicated by physical activity enjoyment scale (PACES) score above 55) in both HIIE protocols may suggest that HIIE running may be an appealing exercise model in girls. However, the association between affect and enjoyment was not explored in this study. Furthermore, this study did not document affective responses before exercise, during the recovery periods, or after exercise. Indeed, Ekkekakis and Petruzzello (1999) outlined that when considering the affective response to exercise, it is critical to consider not just how people feel during exercise, but how their affect changes before, during, and after exercise of different exercise intensities. Another limitation is that this study did not contrast affective responses during HIIE to moderate-intensity exercise, which would enable the DMT to be evaluated from an exercise intensity perspective.

Two studies in adults have demonstrated that HIIE protocols lead to an increased experience of negative affect (unpleasant feelings) (Oliveira et al., 2013, Saanijoki et al., 2015). Oliveira et al. (2013) reported that HIIE is associated with unpleasant feelings compared to CHIE in 15 young adults (aged 24 ± 4 years). Unpleasant feelings evoked during HIIE were based on a significant decline in affect responses from baseline (10 minutes before exercise) to 20%, 40%, 60%, 80% and 100% of the total exercise duration compared to CHIE (HIIE, ES= 0.27 to 1.87; CHIE, ES=0.17 to 0.50). The authors (Oliveira et al., 2013) also reported that the HIIE protocol elicited a negative FS score at the end of exercise compared to CHIE (-2.7 ± 2.6 vs. 0.8 ± 2.5 on FS, respectively). Similarly, Saanijoki et al. (2015) have emphasised that while short-term HIIE is effective at improving cardiorespiratory fitness in sedentary men (aged 47 ± 5 years), HIIE increases the exertional stress (i.e. greater perceived of exertion) and unpleasant feelings (i.e. more negative affect, pain and less satisfaction), when compared to CMIE. The authors (Saanijoki et al., 2015) suggested that the increase in anaerobic metabolism during HIIE could negatively influence the resulting affective responses during HIIE which may limit adherence to this form of exercise in the future.

Negative affective evaluations during HIIE support a psychologically aversive nature of HIIE and may lead to poor exercise maintenance and adherence as postulated by the DMT. However, the appropriateness and implementation of the HIIE protocols adopted in these studies are questionable. For example, Saanijoki et al. (2015) utilised the Wingate-based 'all out' SIT protocol (4-6 x 30 s of all-out cycling efforts at approximately 180% of PPO with 4 minutes recovery) as their HIIE training intervention. As discussed in Chapter 1, the SIT model is just one of many possible permutations in HIIE protocols and may evoke high perceptual stress (effort) and may not be safe, tolerable, or appealing for some individuals. Also, the practical application of the HIIE protocols (~ 7 x 2 minutes at 100% of $\dot{V}O_{2max}$ interspersed with ~ 60 s of active recovery) used by Oliveira et al. (2013) is questionable, as only 50% of their participants completed the task. Findings from Oliveira et al. (2013) also shows that HIIE work intervals performed at maximal exercise capacity (e.g. 100% of $\dot{V}O_{2max}$ and 100% of MAS) could elicit feelings of displeasure, as has been shown by Thackray et al. (2016) in adolescents girls. Thus, the strenuous nature of the HIIE protocols used in these studies could explain the resulting negative affect responses.

Also, studies by Saanijoki et al. (2015) and Oliveira et al. (2013) did not evaluate the affective responses during the HIIE recovery interval to capture any possible rebound phenomena that might occur during low-intensity exercise as predicted by the DMT (Bixby et al., 2001, Ekkekakis et al., 2005b).

In contrast to the above, there are reports that HIIE is experienced as more pleasant than CHIE, but less (or equally) pleasurable than CMIE (Jung et al., 2014, Kilpatrick et al., 2015a, Niven et al., 2018). Thus, HIIE protocols may not elicit prominent and entirely unpleasant feelings. For example, Jung et al. (2014) reported that a practical model of HIIE (cycling with 10 x 1 minute at ~ 90% HR_{max} with 1 minute of active recovery) evoked more pleasurable feelings than CHIE (cycling at ~ 80% PPO for 20 minutes), but less pleasurable feelings than CMIE (cycling at ~ 40% PPO for 40 minutes) in physically inactive men (aged 30 ± 12 years) and women (age 35 ± 16 years). They also showed that the resulting affective responses remained positive across all HIIE work intervals (2.5 and 0.4 on FS in the first interval, and at the end of the work interval, respectively) and HIIE elicited greater post-enjoyment measured by PACES compared to CMIE (ES= 0.43). Similar results have been found in young adults (aged 22 ± 3 years) performing continuous (i.e. 20 minutes cycling at 20% below VT or at VT) and interval exercise (i.e. 10 x 1 minute at VT or 20% above VT with 60 s of active recovery) (Kilpatrick et al., 2015a). They showed that interval exercise protocols, regardless of exercise intensity, produced affective responses (e.g. 2.5 ± 1.4 on FS) that are equal to CMIE (e.g. 2.4 ± 1.4 on FS) and more pleasurable than CHIE (1.0 ± 2.1 on FS). Kilpatrick and colleagues (2015a) reported that CHIE consistently elicited the lowest enjoyment and was significantly lower than all other conditions at all time points above 20% of exercise completion (ES= 0.4–0.8). The authors used a single-item exercise enjoyment scale (EES; Stanley and

Cumming, 2010) to track the changes in enjoyment during exercise bout. Again, although studies by Jung et al. (2014) and Kilpatrick et al. (2015a) reported both affective and enjoyment responses after or during HIIE, respectively, the association between these two factors was not explored. More recently, in an effort to establish the affective responses during and after a reduced volume HIIE protocol, Niven et al. (2018) compared affective responses to HIIE (10 x 6 s cycle sprints with 60 s recovery), CMIE (cycle at 85% of VT for 30 minutes) and CHIE (cycle at 105% of VT matched with CMIE for total work performed) in twelve untrained males ($\dot{V}O_{2max}$= 48.2 ± 6.7 ml·kg^{-1}·min.$^{-1}$; aged 25 ± 7 years). Although, Niven and colleagues (2018) adopted the SIT model for HIIE protocol, it was reported that affect responses during HIIE were similar to CHIE and CMIE (ES= 0.18 and 0.66 at 100% of exercise, respectively) and remained positive across the HIIE session (above 0.8 on FS). The differences in affect responses reported by Niven and colleagues (2018) compared to the other SIT study (e.g. (Saanijoki et al., 2015)) may be due to the duration of the work intervals used. Indeed, Martinez et al. (2015) reported that HIIE of short work duration (i.e. less than 60 s) may not elicit significant disruptions to homeostasis and predicted outcomes of negative affect experienced compared to longer work durations (i.e. 120 s). However, the enjoyment responses during and after HIIE were not included in the Niven et al. (2018) study.

Taken collectively, the evidence indicates that HIIE may generate positive affect responses, but the available data are limited to the comparison of affect responses during continuous and interval type of exercise, which would enable the DMT to be evaluated from the interval exercise perspective. Moreover, as Jimenez-Pavon and Lavie (2017) propose, moderate-intensity interval exercise (MIIE) may have a practical advantage that could be adopted by larger parts of the population, such as inactive individuals, in comparison to HIIE. This suggests that the intermittent nature of the exercise itself may play an important role in promoting better exercise implementation, maintenance, and adoption rather than exercise intensity per se. Another limitation is that these available studies in adults did not equalise the total work performed during HIIE protocols which limits the independent role of exercise intensity on the affective responses to be evaluated. Documenting this information is important because increasing the exercise intensity above the VT leads to progressively negative affective responses during exercise as proposed by the DMT (Ekkekakis et al., 2005b). HIIE protocols typically have work intervals above the VT which can span the heavy and severe exercise domains. Although available data demonstrates affective responses are dependent on work intensity rather than total work performed (Kilpatrick et al., 2007), the evidence is limited to adult-based study involving CMIE (30 minutes at 85% of VT) and CHIE (an average of 24 minutes at 105% of VT). Therefore, the role of HIIE work intensity on the affective responses is unknown, particularly in relation to youth.

The intensity of exercise is one of the key factors influencing the resulting affective responses, as predicted by the DMT, but few studies have examined this in the context of HIIE. One study compared two HIIE protocols with the work intervals at 70% and 100% PPO in obese sedentary males (age 22.7 ± 3.9 years) (Boyd et al., 2013). They reported that the 100% PPO condition elicited significantly lower affect by the end of the 8th work interval (i.e. decreasing an average of 6.9 ± 2.5 on the FS across from work intervals 1 to 8) compared to the 70% PPO condition (i.e. decreasing an average of 1.4 ± 1.1 on the FS from work intervals 1 to 8). This study reinforces the consideration that manipulating the intensity of the HIIE work intervals may promote the pleasurable sensation or positive affect responses during exercise.

Interestingly, with regards to manipulating exercise intensity, a recent study has examined a novel method of performing ramping exercise from low- to high-intensity (i.e. cycling from 0 to 120% of the VT) or high- to low-intensity (i.e. cycling at 120 to 0% of the VT) in adults (Zenko et al., 2016). They reported that the high-to-low intensity protocol elicited an increase in positive affect whereas the low-to-high intensity protocol elicited a decline in affect responses. The authors also revealed that the high-to-low intensity protocol generated greater post-exercise enjoyment compared to the low-to-high intensity protocol (100.39 ± 11.46 vs. 86.64 ± 16.04 on PACES score, respectively). Interestingly, Zenko et al. (2016) indicated that the changes in FS during exercise significantly predicted post-exercise PACES ($r= 0.58$, $R^2= 0.33$). This finding highlights another potential method of manipulating the direction of exercise intensity to promote positive affective experience, but data are currently limited to continuous exercise. It is possible to integrate low-to-high and high-to-low intensity protocols to HIIE to elucidate the influence of exercise intensity on the affective responses to HIIE in youth. Documenting this information is pertinent as previous studies have consistently shown a gradual decline of affect responses during exercise regardless of the intensity (moderate vs. high) in youth (Stych and Parfitt, 2011, Sheppard and Parfitt, 2008a).

While available research has evaluated the relationship between affect responses and exercise intensity during HIIE, data on cognitive and physiological factors during HIIE have yet to be explored particularly in youth. As highlighted in the previous section (section 2.4.2), an important assumption of the DMT is the predominance of cognitive (e.g. self-efficacy and personality) and physiological (e.g. HR responses) factors that relate to pleasurable and unpleasant feelings, respectively. Nevertheless, data are available indicating that accumulated exercise experience and familiarity to HIIE could substantially influence the cognitive and physiological processes involved in the generation of the affective responses to HIIE. For example, Frazao et al. (2016) examined affective responses during HIIE (i.e. 10 x 1 minute work interval at 90% of MAS, interspersed with 1 minute of active recovery at 30% of MAS) in low and high active (total MVPA 159 minutes vs. 1034 minutes per week, respectively) young adults (aged 25.3 ± 3.6 years). They reported that low active participants elicited the highest negative affect responses at the end of the HIIE work interval compared to their physically active counterparts (low inactive= -2.3 ± 2.0 vs. high active= -0.2 ± 2.3 on FS score), showing that individuals who generated more pleasurable feelings during HIIE do more MVPA compared to individuals with low MVPA. This finding may indicate that an individual's PA or exercise experience may play an important role when evaluating affect responses to HIIE. Indeed, a meta-analytical review by Nasuti and Rhodes (2013) of 56 correlations studies in youth (aged 9-15 years) reported that active individuals or experienced exercisers may be able to draw upon their overall PA experiences rather than relying solely on affect responses as an indicator of their capability and motivation to adhere or maintain future PA behaviour. Therefore, it is pertinent to elucidate the affective changes during HIIE in low active individuals because it could enhance the generalisability and practicality of HIIE implementation that are substantially required in youth.

2.5 Influence of cognitive factors to the affective responses

The DMT proposes that cognitive factors are unique to the individual and they are likely to be influenced by self-efficacy, personality traits, goal achievement and prior exercise experience (Ekkekakis, 2003). In order to identify the factors that contribute to the variability of affect responses between individuals during exercise, research has investigated personality traits and self-efficacy as the cognitive factors that underlie the affective responses to exercise (McAuley and Courneya, 1992, Schneider and Graham, 2009).

Personality refers to individual-specific patterns of thought, behaviour and action (McCrae, 2000). Previous studies have mainly focused on the relationship between personality and exercise behaviour with the volume of PA, as well as long-term health benefits in the adult population (Rhodes & Smith, 2006). For example, a meta-analysis of 33 studies in adults (aged 18 to 77 years old) indicated that extraversion (i.e. tend to be lively, active, sociable, experience positive affect and seek excitement) and neuroticism (i.e. self-conscious, tendency to be emotionally unstable and anxious) as the most consistent personality traits that correlate with the volume of PA (r=0.23 and r =-0.11, respectively) (Rhodes and Smith, 2006). All the studies evaluated by Rhodes and Smith (2006) were based on two major models in personality dimension, namely, the Big Five personality model (i.e. extraversion, neuroticism, openness, agreeableness, and conscientiousness) and Eysenck's theory of personality (i.e. extraversion, neuroticism and psychoticism). Although there is evidence to indicate that the affect experienced (i.e. pleasure or displeasure) during exercise can influence subsequent PA (Rhodes and Kates, 2015), the role that personality can play in how people experience exercise is poorly understood in youth. A single study in adolescents, however, evaluated the role of Behavioural Activation System (BAS) and the Behavioural Inhibition System (BIS) that underpins Gray's model of personality (Gray, 1991). Schneider and Graham (2009b) indicated that individuals with a high BIS (n= 68) and low BAS (n= 63) elicited less positive affect compared to those with low BIS (n= 73) and high BAS (n= 83) during CMIE

(PPO at 80% of VT) and CHIE (PPO at VT) in youth (aged 14.8 ± 0.5 years). The participants with high BIS and high BAS reported 1.8 and 2.5 on FS at the end of CMIE, but -0.3 and 0.4 on FS at the end of CHIE, respectively. According to Gray (1991), individual differences in BIS and BAS traits are related to the neuroticism and extraversion that are central to Eysenck's (1967) personality model. Indeed, Muris et al., (2005) found a significant relationship between BIS and BAS scales with neuroticism (r=0.67 and 0.17, respectively) and extraversion (r=-0.34 and r=0.19, respectively) in 8-12 year olds. Gray (1991) posits that the dimensions of BAS and BIS represent manifestations of the approach and avoidance motivational systems, respectively. Specifically, BAS (approach motivation) individuals are sensitive to stimuli that are typically associated with a sense of reward and positive feelings (e.g. pleasurable and happiness), whereas BIS individuals (avoidance motivation) are sensitive to stimuli that are typically associated with a sense of punishment and negative feelings (e.g. frustration and sadness) (Carver and White, 1994). Therefore, the study by Schneider and Graham (2009b) may suggest that individual BIS and BAS personality characteristics may account for substantial portions of variability in affect responses during exercise in youth, although this has yet to be explored for HIIE.

Another potential theoretical explanation for exercise-related affective change involves self-efficacy. Self-efficacy, embedded within social cognitive theory, can be defined as one's confidence to successfully execute a specific behaviour required for a specific outcome (Bandura, 1986, Bandura, 1994). Furthermore, self-efficacy not only measures one's judgment of the capability to perform health-related behaviours (e.g. PA and exercise) but also measuring one's intention to engage in the health-related behaviour (Bandura, 1986, Bandura, 1994). A previous review of 40 studies has indicated self-efficacy as a prominent personal determinant of adolescents (aged 12-18 years) to engage with PA behaviour (Van der Horst et al., 2007). According to Bandura (1994), affective processes play a significant role to control an individual's perceived self-efficacy over threatening or stressor situations during exercise. Indeed, Ekkekakis (2003) highlighted that numerous authors have proposed self-efficacy as a potential explanation for increases in positive (pleasurable feelings) or negative (unpleasant feelings) exercise-related affect responses when the intensity of exercise presents an appreciable challenge (e.g. proximal or above the VT). Self-efficacy is proposed to influence affect responses via a complex cognitive process of efficacy appraisal. Efficacy appraisal is comprised of: 1) examination of physiological arousal based on past stimulus experience; 2) an appraisal process of the source of physiological arousal; 3) an expressive reaction; and 4) a socially learned labelling of arousal, known as emotion (Bandura, 1986). A systematic review of 11 studies by Rhodes and Kates (2015) identified equivocal relationships between affect responses and subsequent exercise self-efficacy; some studies showed a significant positive relationship (Rose and Parfitt, 2012, McAuley and Courneya, 1992) while others showed no significant relationship (Treasure and Newbery, 1998, Tate et al., 1995). For instance, McAuley and Courneya (1992) study of 88 adults (aged 53.5 ± 5.8 years) revealed that post-exercise self-efficacy contributed 77% (R^2= 0.77) of variance of affect and RPE responses during incremental exercise to exhaustion. This finding may suggest that individual self-efficacy plays an important role in the formation of affect responses during exercise. Indeed, previous studies that have reported no relationships between affect responses and post-exercise self-efficacy may be because affect responses were measured following exercise completion (Treasure and Newbery, 1998, Tate et al., 1995) rather than during exercise itself.

However, McAuley and colleagues (1992) found that changes in self-efficacy were related to changes in affect during the exercise once it attained above 70% HR_{max} during incremental exercise, suggesting self-efficacy to be most influential in the face of aversive stimuli.

Collectively, there is evidence to indicate that affect evaluation depends upon an individual's cognitive factors such as personality traits and self-efficacy. However, this observation was made during incremental exercise to exhaustion and continuous exercise where high-intensity exercise was perceived as unpleasant. The available studies also suggest that the different exercise intensity could influence an individual's cognitive factors. However, it is currently unknown whether affective responses during HIIE are related to changes in personality traits and self-efficacy in youth. Documenting this evidence is important as perceptions of either to maintain or enhance the positive affective response during exercise at a given intensity may involve the interaction of an individual's cognitive and physiological factors (Rose and Parfitt, 2007).

2.6 Physiological and affect responses to exercise

The DMT postulates that high-intensity exercise is likely to produce negative affective responses (unpleasant feelings) across the exercise bout due to the predominance of interoceptive cues related to the metabolic strain (e.g. increased in HR) (Ekkekakis, 2003). For example, Acevedo and colleagues (1994) reported that the correlation between affect valence (measured by FS) and HR_{max} was gradually strengthened from 0.08, to -0.65, during increasing running speeds (60, 70, 80, 90, and 95% of each participant's personal record in the mile run) in 7 males and 9 females, respectively (males = aged 20.7 ± 0.4 years; females = aged 19.7 ± 0.5

years). In contrast, no relationship was found during the runs below and at the VT, indicating an increasingly stronger association between affective and physiological responses as the exercise intensity increases. Ekkekakis (2003) also reported that the highest percentage of HR_{max} generated during exercise accounted for ~ 30% of the variance in changes in affect responses over the course of the three runs (i.e. constant speed at intensity below, at, and above the VT) in 30 adults. The aforementioned findings may suggest that the variance in affective responses during high-intensity exercise is accounted by physiological responses, particularly by HR, although this has yet to be explored in youth.

2.6.1 Physiological responses to high-intensity interval exercise

Despite the emerging body of evidence supporting the decrease in affective responses (decrease in pleasurable sensations) during HIIE, data are limited in terms of examining physiological changes (e.g. HR response) during different HIIE protocols (e.g., intensity and duration) and their association with affective responses in youth. Data are however, available indicating the association between negative physiological cues, such as pains and aches (Stych and Parfitt, 2011), with a decline in affect experienced during CHIE in youth, but the relationship between affect and HR responses during HIIE remained unclear. Therefore, elucidating the changes in affect responses during different HIIE protocols (e.g. work intensity) and their association with HR responses is important as different HIIE protocols can influence physiological responses in youth (Tschakert and Hofmann, 2013). Indeed, the intensity (e.g. low vs. high) and duration of HIIE protocols will alter the pattern of the cardiorespiratory, $\dot{V}O_2$ and HR responses, throughout the exercise (Åstrand et al., 1960, Christensen et al., 1960). For example, Tucker and colleagues (2015) compared physiological responses between HIIE with a long (i.e. 4 x 4 minutes of work interval design to elicit 90 – 95% HR_{max} protocols interspersed with 3 minutes of active recovery) and short (i.e. 16 x 1 minute of work interval design to elicit 90 – 95% HR_{max} protocols interspersed with 1 minute of active recovery) work durations in recreationally active adults (aged 26.5 ± 4.6 years). The authors found significant increases in $\dot{V}O$ for the first two work intervals without further increases during subsequent intervals of a 16×1 minute HIIE protocol in men and women. However, much higher $\dot{V}O_2$ responses (90–99% $\dot{V}O_{2max}$) were found during a 4×4-minutes HIIE protocol when compared to the 16×1 minute protocol (~76– 85% $\dot{V}O_{2max}$). They also reported greater HR_{max} during HIIE with a 4×4 minutes HIIE protocol as compared to HIIE with a 16×1 minute HIIE protocol. Another study of overweight/obese, sedentary males (age 22.7 ± 4.3 years) by Boyd et al. (2013) revealed that greater peak $\dot{V}O_{2max}$ and peak HR_{max} during a HIIE protocol (8-10 x 1 minute work interval interspersed with 1 minute recovery interval) performed at 100% PPO as compared to HIIE protocol performed at 70% of PPO.

Studies that assess acute cardiorespiratory responses in adolescents during HIIE are limited. These observations are based on the fact that previous HIIE studies report the average cardiorespiratory response to the entire HIIE protocol rather than on an interval-by-interval basis, which does not allow an in-depth quantification of the HIIE protocol, especially in relation to the affective evaluations during exercise (Bond et al., 2015a, 2015b, 2015c). One study, however, examined HR responses during HIIE involving adolescents aged 14.0 ± 0.3 years (Taylor et al., 2015). In this study, the author reported 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 that incorporated 4 x 45 s of maximal exercise with 90 s recovery. However, currently it is unknown how altering exercise protocols during HIIE may influence the intensity-affect responses in healthy adolescents or whether these affective responses are related to changes in physiological responses such as HR.

2.6.2 The role of prefrontal haemodynamic to exercise

The DMT predicts that the influence of physiological factors may hinder the ability of the PFC to control cognitive and affect processes, resulting in more negative affect (Ekkekakis, 2003). A review by Ekkekakis (2009) indicated that PFC haemodynamic responses (measure by near-infrared spectroscopy (NIRS)) during exercise could offer promising insight concerning the cognitive control of affective responses to exercise. Indeed, NIRS is a non-invasive method to quantify PFC haemodynamic responses and has an acceptable signal-to-noise ratio during dynamic exercise (e.g. cycling) compared to other neuroimaging methods such as electroencephalography (EEG) and functional magnetic resonance imaging (Ekkekakis, 2009).

Available data demonstrates the link between PFC and affect responses, but the evidence is mainly limited to incremental test to exhaustion in adults. For example, Tempest and colleagues (2014) examined a potential mechanistic link between affect and the PFC during incremental test to exhaustion in healthy adults using NIRS. They reported that changes in cerebral oxygenation (ΔO_2Hb) were negatively correlated with changes in affect in healthy adult individuals at intensities above the VT. The authors argued that lower activation in the PFC in the presence of a negative affective response may reflect decreased cognitive control processes towards a less positive affective response. It has been proposed that that lower neural activation in the PFC is associated with a reduced, or plateaued, cerebral O_2Hb in the presence of increased cerebral deoxygenation (HHb) (Ekkekakis and Acevedo, 2006). According to the transient hypofrontality hypothesis (Dietrich, 2006), reduced PFC activity occurs due to the shifts in the metabolic resources, such as oxygen delivery, to the subcortical areas of the brain, driven by the intensified sensory body input (e.g. increased in HR and RPE).

Previous studies have consistently shown that a decrease in neural PFC activation is associated with reduced oxygen availability due to decreases in cerebral blood flow (Bhambhani et al., 2007, Rooks et al., 2010). This means that a greater increase in fractional oxygen utilisation (reflected by an increase in cerebral HHb and reduced cerebral O_2Hb through NIRS) is needed to meet metabolic demand, and this typically occurs at exercise intensity above the RCP point (Bhambhani et al., 2007, Rooks et al., 2010). Currently, there is no data examining the relationship between affective evaluation and NIRS outcomes of PFC haemodynamics in youth, but data are available on NIRS outcomes during incremental exercise to exhaustion. Ganesan et al. (2016) who used NIRS to examine left PFC oxygenation in 11 young males (aged 15.3 ± 2.1 years) during incremental cycling until exhaustion. The authors reported increases over baseline in both PFC O_2Hb and HHb across total exercise time with the greatest increase observed at 80% of total time. However, the oxygen saturation in PFC declined after the RCP and this finding was reinforced by a strong positive correlation between timing of RCP and decline in O_2Hb (r=0.84). This study (Ganesan et al., 2016) highlights the typical pattern of NIRS measurements in the PFC during incremental exercise in children (aged 10.3 ± 2.1 years) by showing an increase in both O_2Hb, and HHb with increasing intensity, with a possible decline in oxygen saturation and O_2Hb at the highest intensities (Luszczyk et al., 2011). These findings could potential suggest a potential mechanistic link between PFC and affect responses during incremental test to exhaustion as suggested by Tempest and colleagues (2014). However, the pattern of PFC haemodynamics in relation to changes in affect response during HIIE is currently unknown in youth.

2.7 Enjoyment responses to physical activity in youth

As highlighted in section 2.4.4, enjoyment responses to exercise may also be related to changes in the affect responses. Perceived enjoyment is one of the consistent modifiable psychological factors of PA determinants and has been documented to have a moderate positive correlation (e.g. r=0.38) with levels of PA in children and adolescents (Sallis et al., 2000, Butt et al., 2011, Bai et al., 2018). Exercise enjoyment can be referred to as a positive response to the movement experience that reflects subjective feelings such as pleasure, preference and fun (Wankel, 1993). Kimiecik et al. (1996) argued that enjoyment is an optimal psychological state that leads to performing an activity primarily for its own benefit or because of interest. Therefore, enjoyment is emotionally-based and involves significant cognitive influences in terms of the totality of the experience, such as self-relevance and abilities to achieve goals, and the existing environmental context (Lazarus, 1991, Wankel, 1993). Consequently, affect and enjoyment represents distinctive concepts, with affect responses involve general feelings that are independent of the cognitive processes, whereas enjoyment (emotional experience) is elicited after a cognitive appraisal process during which a stimulus is recognised as either beneficial or detrimental to the person.

There is evidence in paediatric groups that perceived enjoyment is a predictor of both the intention to engage in PA and actual participation in PA (Craig et al., 1996, DiLorenzo et al., 1998). A review conducted by Allender et al. (2006) of 24 qualitative studies revealed that exercise enjoyment could serve as a potential mediator for promoting youth PA as it may influence future exercise participation and non-participation rather than the perception towards the health benefits. This evidence is supported by a self-determination theory (SDT) framework which is used as a theoretical framework for investigating the relationship between motivation and PA (Deci and Ryan, 1985). The SDT framework illustrates that intrinsic motivation exists when the behaviour is viewed as interesting or enjoyable and can be categorised as an autonomous form of motivation. An autonomous form of motivation is positively related to sustained health-promoting behaviours. Indeed, a meta-analysis found that intrinsic motivation such as enjoyment has a moderate positive association with PA levels (r= 0.27 to 0.38) in children and adolescents (Owen et al., 2014). Consistent with this finding is a descriptive study by De Bourdeaudhuij et al. (2005) of 6,078 children aged 11-19 years who reported that the perception that PA was fun significantly related to higher levels of PA (r= 0.41). Furthermore, a cross-sectional study by Haverly and Davison (2005) that examined factors that motivate adolescents to be physically active found that personal fulfilment, which included the factor of enjoyment, was the strongest and most consistent motivating factor for PA in 202 boys and girls (aged 12.7 ± 0.8 years). These collective findings demonstrate enjoyment as a consistent and significant predictor of youth PA.

Rose and Parfitt (2007) argued that excitement, enjoyment, and positive feelings can be achieved if an individual perceives that they have the ability to complete an exercise session wherein they are comfortably challenged. Furthermore, it has been proposed that for youth, an increased feeling of enjoyment during PA has been linked to perceived success once they can succeed at experiences they find challenging (Martens, 1996). This may suggest the importance of evaluating the challenge posed during HIIE as either extremely or comfortably challenging, which could potentially enhance or attenuate the enjoyment response in youth.

2.7.1 Enjoyment responses to acute high-intensity interval exercise

In the first study to be published concerning the enjoyment level during interval exercise with a paediatric group, Crisp et al. (2012) investigated normal weight and overweight 8-12 year old boys and their enjoyment levels measured using a modified version of PACES during interval exercise (Motl et al., 2001). They revealed no differences in post-enjoyment levels, following 30 minutes of either continuous cycling at the maximum rate of fat oxidation, or with the addition of 4 s of sprint interval exercise every 2 minutes. Despite similar post-enjoyment, the authors revealed that participant's preferred short sprint-interval exercise than continuous cycling alone. Further to this, several studies of adolescent boys and girls (aged 13-15 years), examined enjoyment levels in response to acute bouts of HIIE in comparison to CMIE (Bond et al., 2015a, 2015b, 2015c, Cockcroft et al., 2015). Enjoyment responses were measured immediately after exercise using the modified version of PACES for adolescents. Findings indicate that enjoyment responses were greater (or similar) after HIIE sessions, when compared to CMIE (e.g. CMIE= 53 ± 15 vs. HIIE= 64 ± 7; ES= 0.94), despite the greater physiological stress, showing that HIIE may be an attractive and feasible strategy that can promote exercise adherence in adolescents.

Despite evidence showing that HIIE is more enjoyable than CMIE, the potential reasons underlying this disparity are yet to be fully elucidated, with recent debate on the application of HIIE to public health calling for the reporting of individual items on the PACES, signifying which factors were responsible for the elevated enjoyment following HIIE (Biddle and Batterham, 2015). Furthermore, methodologies used in previous HIIE adolescent-based studies have typically assessed enjoyment responses after exercise, but this approach misses dynamic changes that may occur during the exercise. Limiting the investigative scope to comparing before and after exercise responses overlooks the dynamic process of enjoyment change that occurs throughout an exercise session, with the post-exercise measure reflecting an individual's reaction to the completion of an exercise bout, rather than measuring the response to the exercise stimulus itself (Van Landuyt et al., 2000, Ekkekakis et al., 2000). Furthermore, it has been argued that subjective feelings during exercise may predict future PA participation compared to the post-exercise responses (Van Landuyt et al., 2000).

Currently, there are no data available that explores the enjoyment responses related to the individual items of the PACES, the temporal pattern of enjoyment responses occurring during HIIE, and time course of changes in enjoyment after HIIE in adolescents. However, a single study has evaluated enjoyment responses along with affective responses in adults (Martinez et al., 2015). This study observed three different HIIE protocols that corresponded to 30 s, 60 s, and 120 s of work intervals performed at 60% of the difference between VT and maximal capacity interspersed with 30 s, 60 s, and 120 s of recovery intervals in overweight and obese adults (aged 25.5 ± 3.5 years). They reported that HIIE with 30 s and 60 s of work interval duration elicited greater positive affect and enjoyment responses compared to HIIE with 120 s work intervals (ES range= 0.5-0.6). This finding reveals that changes in enjoyment responses during HIIE are dependent on the type of HIIE protocol and somewhat parallel to the changes in affect responses during exercise. However, the relationship between affect and enjoyment response during HIIE were not evaluated in this study.

2.7.2 Enjoyment and affect responses to exercise

Despite the apparent distinctions between affect and enjoyment, data are available supporting a close correspondence between these variables. Raedeke (2007) study of 105 females (aged 19.3 ± 1.7 years) reported that post-enjoyment responses (measured using PACES) were positively related to increases in positive affect responses (e.g. vigour), but that they were unrelated to changes in negative affect states (e.g. anxiety) during 30 minutes of aerobic exercise (note: the protocols used were not reported). The author argued that perceived enjoyment generated after exercise seems to play a role in interpretation of positive affect. Indeed, evidence suggests the importance of incorporating measures that tap positive feeling states (e.g. vigor and energetic) when delineating the role of enjoyment (Berger and Motl, 2000). However, Readeke (2007) only observed affect before and after exercise which limits delineation of the relationship between affect and enjoyment responses during exercise. Decker and Ekkekakis (2016) found that greater post-enjoyment responses in CMIE in comparison to HIIE were positively correlated to the slope (incline/decline) of affect responses (r= 0.58), and the affective responses at the end of exercise (r= 0.46) in 24 obese females (aged 39.3 ± 11.2 years). This indicates that positive/negative affective responses may facilitate greater/less enjoyment after the exercise. Indeed, as suggested by Fredrickson and Kahneman (1993), the affect slope (decline/incline rate) and end affect are the most consequential stimulus, and both are representative of the overall interpretation of an exercise session (Hargreaves and Stych, 2013, Parfitt and Hughes, 2009) to predict future exercise adherence (Rhodes and Kates, 2015).

While enjoyment and affect responses are related, they are dissimilar constructs, and enjoyment responses are not an explicit consideration within the DMT; both are important exercise perceptions and thus relevant considerations in efforts to understand the exercise experience. Currently, there are no studies that explore the enjoyment responses during and after HIIE in relation to affective responses in adolescents. Elucidating this information is needed as positive affective responses during exercise may lead to greater enjoyment of an exercise session and could then play an important role in predicting exercise maintenance (Raedeke, 2007, Schneider and Cooper, 2011).

2.8 Perceived exertion to exercise in youth

Another important factor that may influence affective responses during exercise is the perceived exertion. Perceived exertion can be defined as the act of detecting and interpreting various sensations of the subjective intensity of effort, discomfort, strain and fatigue which may arise from the body during exercise (Borg, 1962; Noble & Robertson, 1996). Robertson & Noble (1997) argue that perception of exertion involves integrating somatosensory cues from the peripheral muscles and joints, cardiopulmonary system, and neurosensory pathways associated with the higher centres of the brain. Also, the perception of exertion may also be systematically influenced by other factors such as sociological- or psychological factors related to emotional state and prior exercise experience, among others (Noble & Robertson, 1996). Consequently, it appears that the perception of exertion during exercise is regarded as an active process, wherein cognitive, behavioural and physiological functions act to modulate the intensity of the perceptual signal relative to the exercise demand (Noble & Robertson, 1996; Rejeski, 1985).

A review by Groslambert and Mahon (2006) of 38 studies on perceived exertion in children and adolescents (aged 8-18 years) revealed that RPE generated during an incremental test to exhaustion and steady-state submaximal exercise are valid for use with children and adolescents during various types of PA or exercise. Previous studies have typically showed that perceived exertion tends to increase over time during constant-speed continuous exercise or during incremental exercise to exhaustion regardless of exercise intensity (Groslambert and Mahon, 2006). Although research has documented perceived exertion to HIIE sessions to support an increase of RPE over the work intervals (Bond et al., 2017), the available HIIE studies report the selected time point or average perceived exertion to the entire HIIE protocol, rather than by an interval by interval basis. This methodological approach does not allow an in-depth quantification of the HIIE protocol, including the recovery and work intervals. Parfitt and Eston (1995) have shown that the timing of the RPE measurement is important if a true reflection of the exercise intensity is to be obtained, as RPE may vary at given points in time at a given exercise intensity especially in non-steady state conditions (e.g. intermittent exercise). The authors also highlighted that the change in RPE reflects the changes in affect responses across the exercise bout, indicating the relationship between these two factors.

2.8.1 Perceived exertion and affect responses to exercise

Data are available showing an inverse association between affect and perceived exertion responses, but these are limited to adult-based studies. For instance, Acevedo et al. (1994) reported that higher RPE was associated with a lower affect at high intensities of 1200 metre and 1400 metre running (95% of a participant's personal record in the mile run) in 7 males and 9 females, respectively (males = aged 20.7 ± .4 years; females = aged 19.7 ± 0.5 years). This finding is reinforced by a significantly negative relationship (r= -0.59) between affective responses and RPE during high-intensity running, but not during moderate-intensity running (80% of the participant's personal record in the mile run). Frazao and colleagues (2016) recently showed significant negative correlations between RPE and affective responses during a HIIE protocol consisting of 10 x 1 minute work intervals at 90% of MAS interspersed with 1 minute of active recovery at 30% of MAS in active and inactive adults (r = -0.74 for the active groups and r = -0.51 for the inactive group). The observations between affect and RPE during HIIE are consistent with Oliveira et al. (2015) who proposed that the affective response to exercise is not only influenced by the physiological responses, such as HR, but also by how the individuals perceive this intensity during CHIE and HIIE.

An alternative explanation of the relationship between affective responses and RPE during HIE could be linked to the global explanatory model of perceived exertion. According to this theory, physiological responses to an exercise stimulus serve as initial mediators of intensity, which the sensory cortex then interprets as perceptual signals of exertion (Robertson and Noble, 1997). This cognitive process is regulated by psychological characteristics, past experiences, and by the current context of activity. Both physiological (peripheral) and psychological (central) cues interact prior to the arrival of sensory information to the sensory cortex (Rejeski, 1985). However, when exercising at a high-intensity when the ability to attend multiple sources is limited, physiological cues, such as HR, will be the most pertinent and may dominate in the determination of RPE. This is consistent with the DMT which predicts that affect responses during high-intensity exercise will be predominantly influence by interoceptive/physiological factors.

There is evidence that demonstrates a relationship between RPE and affective responses, but the relevant research is limited to adult populations, and little is known about these relationships in paediatric studies, especially during HIIE. The research is also limited in terms of the relationship between affective responses and RPE during HIIE protocols with different work intensities. These are pertinent research areas, given that the differences in HIIE protocols may also influence the session RPE responses (Kilpatrick et al., 2012). However, it is currently unknown how altering the work intensity during HIIE may influence the intensity-affect responses in healthy adolescents and whether these affective responses are related to changes in RPE.

2.9 Summary and experimental aims of each study

Despite the potential of HIIE in terms of promoting health benefits in youth, the adoption of this exercise protocol has been criticised mainly because HIIE may evoke negative affect responses, a lack of enjoyment, or greater exertional stress in participants. Consequently, this may lead to poor implementation, uptake, and maintenance of this exercise modality. Paradoxically, adolescent respondents report a higher level of enjoyment after HIIE when compared to CMIE, but affective responses to HIIE have not been measured. Although affective valence and enjoyment are related (Raedeke, 2007), they are not identical constructs; affective valence arises without significant cognitive elaboration. Furthermore, enjoyment is not an explicit consideration within the DMT. Both are important exercise perceptions and thus are relevant considerations in the effort to understand the exercise experience. There is clear evidence, at least from continuous exercise protocols, that high-intensity exercise evokes negative affect (unpleasant feelings) due to elevated physiological (e.g., increased breathing rate and HR) and exertional (i.e. RPE) stress, providing support to the tenets of the DMT (i.e. relationship between exercise intensity and affective responses) in adolescents. Given that pleasant exercise can improve adoption to prescribed exercise programmes and may promote future exercise behaviour (Rhodes and Kates, 2015), it is crucial to evaluate the affective responses during HIIE. Furthermore, if adolescents find HIIE protocols to be unpleasant, this protocol is unlikely to be a useful strategy to improve health. However, individual cognitive factors may contribute to the potential unpleasant/pleasant feelings during HIIE. Considering the literature cited in this review, there is a clear rationale for evaluating affective responses to HIIE protocols and examining associations with different physiological and perceptual responses such as enjoyment and perceived exertion. Given the current gaps in the literature, the current thesis proposes to undertake five original studies, as follows:

Study One

To examine the acute cardiorespiratory (HR and $\dot{V}O_2$) and perceptual (RPE) responses of adolescents during an HIIE protocol, and to explore which individual items from the PACES contribute to elevated enjoyment following HIIE compared to CMIE. It is hypothesised that:

- Cardiorespiratory and perceptual responses will increase across all HIIE work intervals, but there will be no apparent sex differences in cardiorespiratory and perceptual responses.
- HIIE will elicit greater enjoyment after HIIE in comparison to CMIE, but there will be no sex differences in enjoyment responses.

- CMIE will elicit a greater score on negative items in PACES, with responses such as ‘I feel bored’, but HIIE will elicit a greater score on positive items in PACES, such as ‘It’s very exciting’.

Study Two

To investigate the affective, enjoyment and perceived exertion responses to HIIE and MIIE in adolescents. It is hypothesised that:

- Affective responses will decrease more during HIIE than MIIE but remain positive in both exercise conditions (i.e. remain pleasurable).
- Enjoyment will be similar between conditions during exercise but greater enjoyment will be apparent after HIIE than MIIE.
- There will be a strong negative correlation between enjoyment, perceived exertion, and physiological responses (e.g., HR) with the affective responses during HIIE but not MIIE.

Study Three

To evaluate the affective, enjoyment and perceived exertion responses to HIIE differing in work intensity (ranging from 70 to 100% peak power) in adolescents. It is hypothesised that:

- Affective responses will decrease across all HIIE protocols, but a steeper decline in affective responses will be apparent during HIIE with the highest work intensity (i.e. 100% peak power).
- Enjoyment will be similar during all HIIE protocols, but less enjoyment would be apparent after HIIE protocols with the highest work intensity.

- There will be a strong negative correlation between enjoyment, perceived exertion, and physiological responses with the affective response across all HIIE protocols.

Study Four

To evaluate affective, enjoyment, perceived exertion, and prefrontal cortex haemodynamic responses to HIIE, employing either a ‘low-to-high’ or ‘high-to-low’ manipulation of the work intensity in adolescents. It is hypothesised that:

- Affective and enjoyment responses will increase during HIIE with a high-to-low intensity protocol near the end of HIIE work intervals but will decline during HIIE with a low-to-high intensity protocol.
- There will be an elevated cerebral oxygenation towards the end of HIIE with a high-to-low intensity protocol compared to HIIE with a low-to-high intensity protocol.
- There will be a strong positive correlation between affect responses with cerebral oxygenation across all HIIE conditions.

Study Five

To evaluate the influence that cognitive factors, such as self-efficacy and personality traits (low vs. high BAS or BIS), have on affective, enjoyment, and perceived exertion responses to HIIE in adolescents. It is hypothesised that:

- High BAS (and low BIS) and high-efficacy individuals would experience more positive affective responses in comparison to low BAS (and high BIS) and low-efficacy individuals during HIIE.

- High BAS (and low BIS) and high-efficacy individuals would experience greater enjoyment compared to low BAS (and high BIS) and low-efficacy individuals during HIIE.
- High BAS (and low BIS) and high-efficacy individuals would experience lower perceived exertion compared to low BAS (and high BIS) and low-efficacy individuals during HIIE.

CHAPTER 3: General methods

This chapter will delineate the methods used in the experimental studies outlined in Chapters 4-8 of the thesis, which represent studies 1-5 respectively. The specific methodological aspects unique to each individual study are discussed in the relevant chapters.

3.1 Ethics approval

All experimental studies presented in Chapters 4-8 received ethics approval by the Sport and Health Sciences Ethics Committee at the University of Exeter (Proposal Ref No: 160217/B/04, 161207/B/03, 170712/B/02, see Appendix 1). For the ethics approval purposes, all the participants were informed of the potential risks of the exercise sessions and performing maximal exercise (e.g. muscle soreness, syncope) However, the associated risks were low, and are typical with performing vigorous exercise (e.g. HIIE and maximal exercise). To help minimise these risks however, researchers ensured that the protocols and procedures were undertaken professionally and the participants' health and well-being were treated as priority. Information about participants' health status was obtained before the commencement of exercise using a standard health screening form for children (Appendix 2). All equipment were stored and maintained accordingly to a high-standard, and operating procedures were adhered to for all measurements performed. Before commencement, participants were fully familiarised with the experimental protocol and measurement tools. Warm-up and cool-down periods were incorporated. All participants were also free to cease from the exercise testing at any stage, and testing was terminated if participants showed unusual signs of discomfort. A qualified first aider (primary investigator) was available throughout the testing procedures for each experimental study. Participants were also able to withdraw from the study at any time without having any reason. This was clearly stated on the informed consent/assent forms.

All data obtained from each study was stored electronically (in coded form and anonymised) on the student/staff drive space of the University of Exeter's computers which are for security reasons password protected. Data in hardcopy form were also stored in an individualised folder in a secure location which can only be accessed by the researchers involved in the study. Participants/guardians were informed that the outcome of the study may be published but that any data would be anonymised. As the study involved participants less than 18 years of age, participants' assent as well as their guardians/parents' consent were required to take part in the research. Also, all personnel directly involved with the project testing were Disclosure and Baring Service (DBS) checked (enhanced level).

3.2 Participant recruitment and inclusion/exclusion criteria

For the experimental studies presented in Chapters 4-8, participants were recruited from local secondary schools. After an initial discussion with school contacts describing the research questions to be addressed and the associated study requirements, potential participants were approached by the primary researcher during a school assembly to describe the research in more detail. Following the assembly, potential participants were given the opportunity to ask questions to the primary researcher, provided with a study information pack, and asked to discuss the project with their parents/guardians. An example of the information pack contents, including a participant information sheet, participant assent form, parent/guardian consent forms, health screen questionnaire and contact details forms are provided in Appendices 2-3. Adolescents interested in taking part in the project were asked to return the completed parental consent and participant assent form and the health questionnaire to an assigned contact within the school. Parents/guardians were also contacted (via telephone, email, or text messages) to discuss any further questions or concerns they might have about their child's involvement in the project. The procedures, benefits and risks were fully explained to each participant in the participant information sheets as discussed in section 3.1. Participants were recruited into the study if they satisfied the inclusion/exclusion criteria. There were no specific inclusion criteria apart from age between 11 and 15 years for both boys and girls. Exclusion criteria included the presence of any musculoskeletal injury especially to lower limbs, which would prevent participants from cycling or running, inability to understand the study procedures, or the presence of any disease and infection which could alter mood and exercise performance.

3.3 Experimental design

In Chapter 4, the experimental data were obtained from previous work that our group has conducted examining the health benefits of performing HIIE in comparison to work-matched CMIE (Bond et al., 2015a; 2015b; 2015c). The remaining three experimental studies utilised a repeated measures design in which each participant was asked to participate in two (Chapter 5) or three (Chapters 6 and 7) experimental conditions over a 3-4 week period. In Chapter 8, the experimental data were obtained after combining data from Chapters 6 and 7. Data included in Chapter 8 were not presented in the Chapter 6 and 7. All exercise sessions were separated by a minimum two-day rest period and each of the participants was assigned to perform the exercise test at the same time of the day. The first visit of every study was to measure anthropometric variables, determine cardiorespiratory fitness and familiarise participants with the measurement scales. This was followed by experimental visits each involving a different exercise protocol (e.g. CMIE, MIIE and HIIE), the order of which was counterbalanced to control for an order or learning effect. Prior to each experimental condition, participants were also instructed to avoid any organised PA. The experimental studies that are discussed in Chapters 4 and 5 took place in the laboratory facilities at the University of Exeter, whereas the experimental studies in Chapters 6-8 took place in a satellite laboratory in a local school.

3.4 Anthropometry

Standard anthropometric outcomes were obtained in all chapters. Body mass was measured without shoes using a digital scale (Seca 770; Seca Ltd., Hamburg, Germany) to the nearest 0.1 kg, and height was measured barefoot in the Frankfort plane using a stadiometer (Holtain, Crosswell, UK) to the nearest 0.01 m (Nagy et al., 2008). Age and sex specific body mass index (BMI) cut-points for over-weight and obese status were determined from Cole et al. (2000). Percentage body fat was estimated using the subscapular and triceps skinfold sites according to validated age and sex specific equations as follows (Slaughter et al., 1988):

$$\text{Male} = 1.21\ (\text{triceps} + \text{Subscapular}) - 0.008\ (\text{triceps} - \text{Subscapular})^2 - 3.4$$

$$\text{Female} = 1.33\ (\text{triceps} + \text{subscapular}) - 0.013\ (\text{triceps} + \text{subscapular})^2 - 2.5$$

Equation 3.1 The skinfold equations for predicting body fat in 8 – 18 years of age.

Skinfold thickness was measured to the nearest 0.2 mm on the right hand side of the body by the same investigator using a skinfold calliper (Holtain Limited, UK). The skinfold measurement was carried out three times, but not consecutively. The mean of three measurements of each site was used to estimate body fat. This skinfold method has been shown to be valid (i.e. the coefficient of determination, R^2= 0.80; standard error of estimation, SEE= 3.6) for predicting percentage of body fat in children and adolescents (Silva et al., 2013).

3.5 Pubertal status

In Chapters 4 and 5, pubertal status was determined by self-assessment of secondary sexual characteristics using adapted drawings of the five stages of pubic hair development (Morris and Udry, 1980). After a verbal explanation from the lead researcher, the adapted drawings were presented on an information sheet. The participant returned home with the form and circled the most appropriate number before signing and returning the form in a sealed envelope during their next visit to the laboratory. In Chapters 6-8, maturation (somatic) offset from the age at peak height velocity (APHV) was determined from participant age and stature using the modified equations of Moore et al. (2015) (Equation 3.2). Participants were then classified as pre (-1 year), circa (-1 to +1 year), or post (+1 year) PHV.

Maturity of set in boys = - 7.999994+ (0.0036124 x (age x height))

where R^2 = 0.896 and SEE = 0.542

Maturity of set in girls = -7.709133 + (0.0042232 x (age x height))

where R^2 = 0.898 and SEE = 0.542

Equation 3.2 The regressions equations for predicting somatic maturity in boys and girls.

3.6 Cardiorespiratory fitness

In Chapter 5, a combined ramp incremental and supramaximal test to exhaustion was used to establish $\dot{V}O_{2max}$ and VT (Barker et al., 2011) by using a motorised treadmill (Woodway PPS 55 Sport slate-belt treadmill, Woodway GmbH, Weil am Rhein, Germany). Participants began a warm-up against a speed of 4.0 km·h^{-1} for 3 minutes, followed by running at the speed of 6.0 km·h^{-1} with 0.5 km·h^{-1} increments every 30 s until volitional exhaustion, before a 5 minutes cool down at 4.0 km·h^{-1}. Exhaustion was defined whenever the participants terminated the test by pressing a stop button or raised their hand as a signal to stop the test. Participants were provided with verbal encouragement to achieve volitional fatigue and discouraged from holding the handrails during the test. Throughout the incremental test, the treadmill gradient was set at 1% to reflect the outdoor energy cost of running (Jones and Doust, 1996). Immediately 5 minutes after the cool down, participants performed a supramaximal test to exhaustion at 100% of MAS obtained from the incremental test with the treadmill gradient set at 5%. The ramp incremental test to exhaustion has previously been used for determining $\dot{V}O_{2max}$ in adolescents (Thackray et al., 2013, Thackray et al., 2016).

In the studies covered in Chapters 4 and 6-8, a ramp incremental test to exhaustion was used to establish participant $\dot{V}O_{2max}$ and VT by using an electronically braked cycle ergometer (Lode Excaliber Sport, Groningen, Netherlands). Participants were initially briefed on the test protocol and instructed to maintain a cadence between 75 and 85 revolutions per minutes (rpm) throughout the test. Participants began a warmup of unloaded cycling for 3 minute, followed by 15 W increments every 1 minute until volitional exhaustion, before a 5 minutes cool down at 25 W. Exhaustion was defined as a drop in cadence below 60 rpm for 5 consecutive seconds despite strong verbal encouragement (Barker et al., 2011).

In Chapters 4-8, gas exchange and ventilation variables during the cardiorespiratory fitness test and experimental protocols were measured using a calibrated metabolic cart (Cortex Metalyzer III B, Leipzig, Germany). The metabolic cart was calibrated before each measurement, using standard calibration gas (5% CO_2, 17% O_2, Cranlea, 90 Birmingham, UK) and a 3.0 L calibration syringe (Hans Rudolph, USA). 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 intervals. The VT was estimated by using visual analysis at the point where the first disproportionate increase in carbon dioxide production ($\dot{V}CO_2$) relative to increase in $\dot{V}O_2$ during the ramp incremental test to exhaustion. This point was also verified by plotting ventilatory equivalents of CO_2 ($\dot{V}_E/\dot{V}CO_2$) and O_2 ($\dot{V}_E/\dot{V}O_2$) against time, and identifying the point at which $\dot{V}_E/\dot{V}O_2$ systematically increased, independent of an increase in $\dot{V}_E/\dot{V}CO_2$. This was achieved from visual inspection of individual plots of $\dot{V}CO_2$ versus $\dot{V}O_2$ by two independent assessors. This visual analysis method for determining VT had similar test-retest coefficients of repeatability relative to a computerised v-slope method (6.5 % coefficient of variation (CV) and 7.5 %CV, respectively) in a paediatric population (Fawkner et al., 2002).

In Chapters 4 and 5, participants $\dot{V}O_{2max}$ was determined as the highest 10 s average of $\dot{V}O_2$ recorded in either the ramp incremental or supra-maximal test (Barker et al., 2011) (Figure 3.1). A combined ramp and supramaximal test to exhaustion to establish $\dot{V}O_{2max}$ in Chapters 4 and 5 has been validated previously in children (Barker et al., 2011). However, the supramaximal test was not performed in Chapters 6 to 8. Although the supramaximal test was not performed in both chapters, the ramp test alone provides $\dot{V}O_{2max}$ in ~ 90% of cases, as reported by Barker et al. (2011). Therefore, the attainment of $\dot{V}O_{2max}$ was identified as the highest 10 s average of $\dot{V}O_2$ recorded in ramp incremental test. In Chapters 5 to 8, 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-points in youth (Adegboye et al., 2011). Finally, HR_{max} was taken as the highest HR achieved during the ramp incremental test.

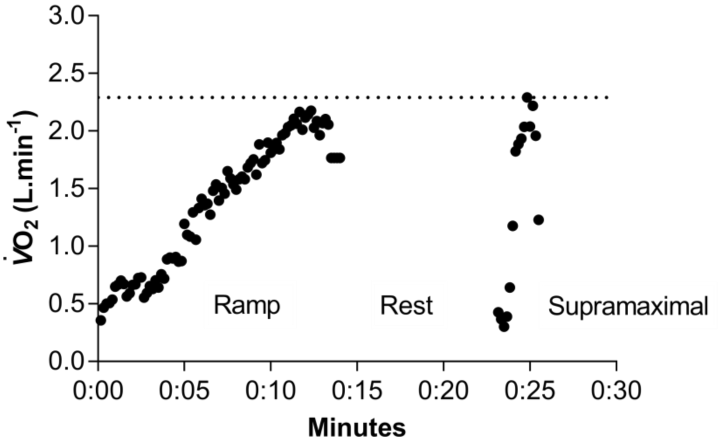

Figure 3.1 Example oxygen uptake trace from a combined ramp and supramaximal test to exhaustion to determine maximal oxygen uptake in a participant. Maximal oxygen uptake was taken as the highest 10 s average oxygen uptake during either the ramp or the supramaximal component of the test. In the example above oxygen uptake reached 2.15 (in litres per minute) during the ramp part of the test and 2.22 (in litres per minute) (~ 3% increase from the ramp test) during the supramaximal bout. Maximal oxygen uptake was therefore taken as 2.22 (in litres per minute) for this participant.

3.7 Physical activity

In Chapters 5-8, participants wore a triaxial accelerometer (GeneActiv GENEA, UK) on their non-dominant wrist for measurement of PA. Participants were asked to continuously wear the device on their non-dominant wrist during the day and night time for seven days following the exercise conditions. The accelerometer was set to record at 100 Hz. 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). This duration of daily wear time must be long enough to remove days when the accelerometer was not worn but short enough to prevent unnecessary days being removed from analyses. Data were analysed at 1 s epoch intervals to establish time spent in light intensity PA, moderate intensity PA and vigorous PA using a cut-off point of ≥ 420 (light), ≥1140 (moderate), and ≥3600 (vigorous) counts per minute, which was developed for youth (Phillips et al., 2013). The wrist GENEA accelerometer revealed good criterion validity at both wrist locations right hand (*r*=0.90) and left hand (*r*=0.91) (Phillips et al., 2013).

3.8 Exercise protocols

The exercise protocols presented in Chapters 4 and 6-8 were performed using an electronically braked cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands). In Chapter 5 the exercise protocols experimental sessions were performed using a motorised treadmill (Woodway PPS 55 Sport slate-belt treadmill, Woodway GmbH, Weil am Rhein, Germany). All the experimental studies presented in Chapters 4-8, employed a HIIE protocol that is commonly used in the paediatric literature (Bond et al., 2017). The HIIE protocol consisted of 8 x 1 minute duration of work intervals interspersed with 75 s of active recovery. This low-volume HIIE protocol was adopted as it has been shown to be a practical and feasible in youth as has been discussed in Chapter 1. The duration of the warm-up (3 minutes), cool-down (2 minutes) and recovery periods (75 s) were standardised across all exercise conditions. Consequently, the total duration of the HIIE protocols was similar across all HIIE conditions (i.e. 22 minutes 15 s). In all experimental chapters, a cut-off point of ≥90 % HR_{max} was used as the criterion for compliance to the HIIE protocol (Taylor et al., 2015).

Chapter 4 was aimed to examine adolescents' acute cardiorespiratory and perceptual responses during HIIE and enjoyment responses following HIIE and work-matched CMIE. The HIIE protocol was compared to a bout of CMIE protocol. The HIIE protocol consisted of 8 x 1 minutes cycling at 90% of the PPO determined during the ramp-incremental test, interspersed with 75 s recovery at 20 W. This HIIE protocol was contrasted to a bout of CMIE performed at 90% of the VT. The duration of CMIE was calculated to match the total external work performed during HIIE for each participant.

Chapter 5 was aimed to examine the acute affective, enjoyment, and perceived exertion responses to HIIE compared with MIIE during running in adolescents. The HIIE protocol consisted of 8 x 1 minute running intervals at 90% MAS determined from the incremental test, whereas the MIIE consisted of between 9-12 1 minute running intervals at 90% VT, where the numbers of MIIE work intervals was calculated to match the distance performed during HIIE for each participant. HIIE and MIIE intervals were interspersed with 75 s active recovery at 4 $km \cdot h^{-1}$.

Chapter 6 examined the acute affective, enjoyment, perceived exertion and cardiorespiratory responses to HIIE with different work intensities using cycling exercise in adolescents. Three different HIIE protocols were examined consisting of 8 x 1 minute work intervals at either 70%, 85%, or 100% of the PPO determined from the incremental test, interspersed with 75 s active recovery at 20 W. The intensity of the HIIE protocols were manipulated but the total work performed across the HIIE conditions was not matched.

Chapter 7 examined the affect, enjoyment and cerebral haemodynamic responses to HIIE with increasing or decreasing work intensities using cycling exercise in adolescents. Three HIIE protocols were used based on a constant, increasing or decreasing intensity of the work intervals. Specifically, the HIIE protocols consisted of: 1) Decreasing: 2 x 1 minute work intervals performed at 100%, 90%, 80% and 70% PPO, interspersed with 75 s recovery at 20 W (total of 8 work intervals); 2)

Increasing: 2 x 1 minute work intervals performed at 70%, 80%, 90% and 100% peak power, interspersed with 75 s recovery at 20 W (total of 8 work intervals); and 3) Constant: 8 x 1 min work intervals at 85% PPO, interspersed with 75s recovery at 20 W. The HIIE protocols were matched for total (external) work performed.

Finally, Chapter 8 evaluated the influence of personality traits and self-efficacy on affect, enjoyment and perceived exertion during HIIE in adolescents. The HIIE protocol consisted of 8 x 1 minute duration of work intervals performed at 85% PPO interspersed with 75 s of active recovery.

3.9 Experimental measures

3.9.1 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, Stych and Parfitt, 2011). Participants were asked to rate how they currently feel on an 11-point bipolar scale, with anchors at zero ("Neutral") and at all odd integers, ranging from "Very Good" (+5) to "Very Bad" (-5) (Figure 3.2). Van Landuyt et al. (2000) report that FS exhibited Pearson’s correlations ranging from 0.41 to 0.59 with the valence scale of the Affect Grid (Russell et al., 1989), and from 0.51 to 0.88 with the valence scale of the Self-Assessment Manikin (SAM; Lang, 1980).

+5	Very good
+4	
+3	Good
+2	
+1	Fairly good
0	Neutral
-1	Fairly Bad
-2	
-3	Bad
-4	
-5	Very bad

Figure 3.2 Feeling scale (Hardy and Rejeski, 1989)

Activation levels were measured using the felt arousal scale (FAS; Svebak and Murgatroyd, 1985). The FAS is a single-item measure of perceived activation, with participants asked to rate themselves on a 6-point scale ranging from 1 to 6, with anchors at 1 'low arousal' and 6 'high arousal' (Figure 3.3). Van Landuyt et al. (2000) report that FAS exhibited Pearson's correlations ranging from 0.47 to 0.65 with the arousal scale of Affect Grid (Russell et al., 1989), and from 0.45 to 0.70, with the arousal of the SAM (Lang, 1980).

1	**Low Arousal** (Relaxation, Boredom, Calmness)
2	
3	
4	
5	
6	**High Arousal** (Excitement, Anxiety, Anger)

Figure 3.3 Felt arousal scale (Svebak and Murgatroyd, 1985)

Participants were given standardised verbal instructions on how to use the scales before undertaking the incremental test and at the start of the exercise session in the experimental Chapters 5-8, using the below sentences:

> ***Feeling Scale:*** *While participating in exercise it is quite common to experience changes in mood. Some individuals find exercise pleasant, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. How does above scenario make you feel during the exercise?*
>
> ***Felt arousal scale:*** *Estimate here how aroused you actually feel. By "arousal" we meant how "worked-up" you feel. You might experience high arousal in one of a variety of ways, for example as excitement or anxiety or anger. Low arousal might also be experienced by you in one of a number of different ways, for example as relaxation or boredom or calmness.*

Affective responses were also assessed from the perspective of the circumplex model (Russell et al., 1989), using a combination of FS and FAS (Benjamin et al., 2012). 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) (Figure 2.1 in Chapter 2).

3.9.2 Perceived enjoyment

In Chapters 5-8, participants rated their enjoyment during the exercise conditions on a 7-point exercise enjoyment scale (EES; Stanley and Cumming, 2010). Participants responded to the statement: “Use the following scale to indicate how much you are enjoying this exercise session” via a 7-point Likert item from 1 (not at all) to 7 (extremely) (Figure 3.4). The ESS has been found to be a valid measure of exercise enjoyment with Stanley et al. (2009) reporting moderate Pearson’s correlations (r=0.41 to 0.49) between the EES and the FS before, during and after cycle ergometer exercise.

7	**Extremely**
6	**Very much**
5	**Quite bit**
4	**Moderately**
3	**Slightly**
2	**Very Little**
1	**Not At All**

Figure 3.4 Exercise enjoyment scale (Stanley and Cumming, 2010)

In Chapters 4-8, enjoyment responses after the exercise conditions were measured using the modified physical activity enjoyment scale (PACES), which is validated for use in adolescents (Motl et al., 2001) (Appendix 4). The PACES includes 16 items that are rated on a 5-point bipolar scale (score 1 = "strongly disagree" to score 5 = "strongly agree"). In accordance with the standardised instructions, respondents were asked to "please rate how you feel at the moment about the exercise you have been doing." Of the 16 items included in the PACES, reverse scoring was used for questions 2, 3, 5, 7, 12, 13, and 16. The score for each item was summed to calculate a total enjoyment score for each exercise protocol. This procedure yielded a possible range of scores from 16 through to 80 with a higher score representing greater enjoyment.

Participants were given standardised verbal instructions on how to answer the PACES questionnaire immediately after and 20 minutes after the exercise session in Chapters 5-8, using the below sentences:

‘’These questions that you are going to answer are not a test. The enjoyment questionnaire includes 16 items that are rated on a 5-point bipolar scale (score 1 = “strongly disagree” to score 5 = “strongly agree”). ***Please rate how you feel at the moment about the exercise you have been doing by CIRCLING the number that best describes your answer.*** *I can help you if you get stuck with any question. You can stop answering the questions at any time and you will not be in trouble. Remember there are no right or wrong answers for these questions, so do not spend too much time on any one item. Only I will see your answers’’*

3.9.3 Rating of perceived exertion

In Chapter 4, RPE was assesses using the 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 (1–10). In Chapters 5-8, RPE was assessed using the validated 0–10 Pictorial Children’s OMNI scale for cycling (Robertson et al., 2000) (Figure 3.5) and running (Utter et al., 2002) (Figure 3.6). The different RPE scale used in the following Chapter 4 was due to the cycle and running format of the OMNI scale compared to step format of the PCERT scale. Validity coefficients between the OMNI RPE scale and $\dot{V}O_2$ and HR ranged from r=0.41 to r=0.94 during incremental cycling ergometer (Robertson et al., 2000) and treadmill (Utter et al., 2002) exercise. The OMNI has a range of numbers familiar to youth (0 to 10) and uses age appropriate verbal expressions as descriptors of exercise effort. Participants respond to the questions, “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).

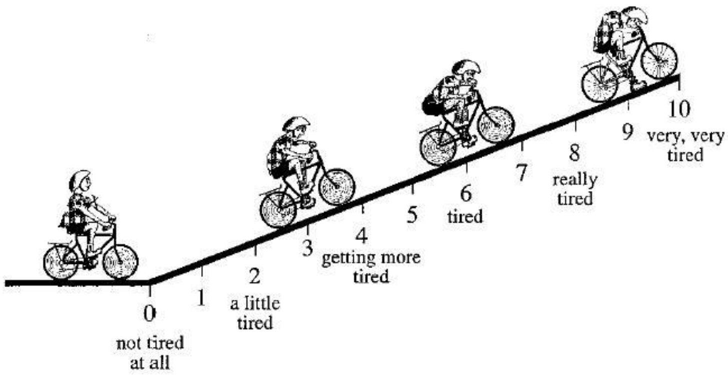

Figure 3.5 Children's OMNI scale of perceived exertion for cycling (Robertson et al., 2000)

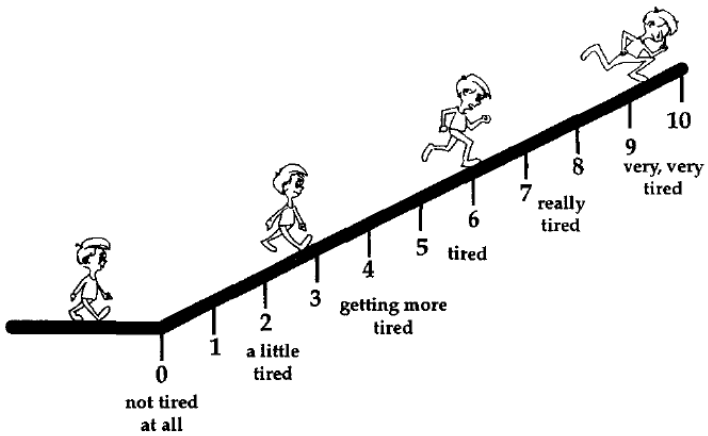

Figure 3.6 Children's OMNI scale of perceived exertion for running (Utter et al., 2002)

Participants were given standardised verbal instructions on how to use the scales before undertaking the incremental test and at the start of the exercise in experimental Chapters 5-8, using the below sentences:

> ***RPE OMNI scale**: What is your rating of **how tired you feel**? This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of tiredness. The rating scale from 0 to 10, where 0 means "not tired at all at all" and 10 means "very, very tired." Try to*

estimate your feeling of tiredness as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and tiredness is important, not how it compares to other people. Please report verbally the number spontaneously from the scale that best describes your level of exertion. Remember, there are no right or wrong numbers. Use both the pictures and words to help select the numbers. Use any of the numbers to tell how you feel when riding the bicycle/running on the treadmill.

3.9.4 Measurement time points

In Chapters 5-8, participants were asked to provide their perceptual responses as described in Table 3.1. FS and FAS were also obtained at the end of every stage during the incremental test to exhaustion to familiarise the participants with the scales. The rating scales were presented on laminated posters only at predetermined time points. All the scales were administered by the same researcher and the scales were presented in the same order during all exercise conditions.

Table 3.1 The time points for each of the measurements

Measurement	5 minutes before	20 s before the end of the warm-up session	20 s before the end of each work and recovery interval	Immediately post-exercise	20 minutes post-exercise
Affect responses measured by FS and FAS	✓	✓	✓	✓	✓
Enjoyment measured by EES		✓	✓		
Enjoyment measured by PACES				✓	✓
Perceived exertion by RPE		✓	✓	✓	✓

FS, Feeling scale; FAS, felt arousal scale; EES, exercise enjoyment scale; PACES, physical activity enjoyment scale; and RPE, Rating of perceived exertion. Where ✓ represents the time points for when each scale was presented during the exercise conditions.

3.9.5 Exercise task self-efficacy

In Chapter 8, participants' confidence in their ability to repeat the exercise they just completed was assessed at 20 minutes post-exercise using a 5-item measure (Appendix 5). Each question anchored the stem ''How confident are you that you can…''. The 5-items were: 1)''perform one bout of exercise a week for the next 4 weeks that is just like the one you completed today?'' 2) ''Perform two bouts of exercise a week for the next 4 weeks that is just like the one you completed today?'' 3) ''Perform three bouts of exercise a week for the next 4 weeks that is just like the one you completed today?'' 4) ''Perform four bouts of exercise a week for the next 4 weeks that is just like the one you completed today?'' 5) ''Perform five bouts of exercise a week for the next 4 weeks that is just like the one you completed today?' Participants responded to each item on a 100-point percentage scale with 10 percent increments that ranged from 0% (not at all confident) to 100% (completely confident). Each of the five item scores was averaged and used as the self-efficacy score. The format of this scale was adopted in a previous study that examined the influence of affect responses to HIIE in adults (Jung et al., 2014) and was created following recommendations made by Bandura et al. (1997). The internal consistencies for the self-efficacy scale in Chapter 8 were excellent (α= 0.93).

3.9.6 Behavioural activation and behavioural inhibition

In Chapter 8, personality traits of the participants were measured using the BIS and BAS scales (Appendix 6). The BAS and BIS consist of 20 items that measure the two primary dimensions (Carver and White, 1994). Items are scored on a four-point Likert-type scale. The measurements include four multi-item subscales that assess sensitivities to signals of impending reward and punishment. The BIS consists of a single subscale that measures the anticipation of punishment (7 items; items no 2, 8, 13, 16, 19, 22 and 24), whereas the BAS consists of three subscales that measures drive (4 items; items no 3, 9, 12, 21), fun seeking (4 items; items no 5, 10, 15 and 20), and reward responsiveness (5 items; items no 4, 7, 14, 18 and 23). Examples of a BIS/BAS questionnaire are provided in Appendix 6. In order to focus on different aspects of incentive sensitivity of BAS as proposed by Carver and White (1994), the reward responsiveness subscale was used to represent the BAS group. This is because previous work in youth has shown that feelings of reward facilitated the post-enjoyment levels in HIIE and related to the positive affect responses during HIIE (Malik et al., 2017). The total score for BAS and BIS were averaged to the number of each item and used as the BAS and BIS score. This scale has been successfully used and validated for children and adolescents (Schneider and Graham, 2009b, Cooper et al., 2007).

3.10 Near infrared spectroscopy

In Chapter 7, cerebral hemodynamics were measured non-invasively using NIRS (NIRO 200 Hamamatsu Photonics, Hamamatsu, Japan). The emitter and detector were encased in a rubber holder with a separation distance of 4 cm. Age-specific differential pathlength factors were calculated using the modified Beer-Lambert equation [i.e. 4.99 + 0.067 ($age^{0.814}$)] to provide a measure of the concentration changes (micromolar; mM) in cerebral ΔO_2Hb, cerebral ΔHHb and tissue oxygenation index (TOI) (Duncan et al., 1996). In line with previous studies in youth (e.g. Ganesan et al., 2016, Luszczyk et al., 2011), the probes were placed over the participant's forehead left hemisphere (dorsolateral prefrontal cortex areas; midpoint between Fp1-F3, of the international 10-20 system for EEG electrode placement). The probes were secured to the skin using a double adhesive sticker. An elastic bandage was placed over the holders around the forehead. A 30 s baseline measure of cerebral hemodynamics was recorded before all HIIE conditions. Baseline measures were subtracted from the data extracted during exercise. Therefore, ΔO_2Hb and ΔHHb represent the change from the baseline in the hemodynamic response at selected points during exercise. The TOI represents a measure of tissue oxygen saturation (the ratio of O_2Hb to total Hb); therefore, adjustments for baseline measures were not required. These variables were time aligned with the gas exchange data obtained during each work and recovery interval and 10 s averages were taken at the end of the work and recovery intervals for further analysis.

3.11 Sample size calculation

For Chapters 5-8, an *a priori* sample size calculation was performed using G-power software (Faul et al., 2007). Reference values taken from the literature (e.g. (Martinez et al., 2015) for the primary outcome of affective responses (i.e. FS score) during HIIE were used to inform effect size statistics, with sample size calculated using 80% statistical power (1-β) and a significance (α) level of 5%. This was based on the ability to detect a medium to large effect (i.e. partial eta squared of 0.09 (medium) to 0.25 (large)) in the affective responses for a condition by interval repeated measures ANOVA. For Chapter 4, no a priori sample size calculation was performed due to the retrospective nature of data analysis. Data were available on 60 participants after combining three previous studies examining the health benefits of performing HIIE compared to work-matched continuous MIE (Bond et al., 2015a; 2015b; 2015c). A total of 6 participants (3 boys) were excluded due to missing gas exchange data and resulted in a final sample of 54 (27 boys) for the study.

3.12 Statistical analyses

Data for all experimental studies were analysed using SPSS (22.0; IBM Corporation, Armonk, NY, USA) and results are presented as mean ± standard deviation (SD), unless otherwise stated. The Shapiro-Wilks test was used to test normality of distribution for the dependent variables. In Chapters 4 and 6-8, descriptive characteristics between boys and girls were analysed using independent samples t-tests. Data were analysed using a two-way repeated measures (Chapter 5 and 8) or mixed model (Chapter 4, 6, and 7) analysis of variance (ANOVA) to examine mean differences in dependent variables between exercise conditions over time and experimental orders in the studies. As the inclusion of sex into the ANOVA model did not reveal a significant interaction effect for dependent variables, data were subsequently pooled in Chapters 6, 7 and 8. Additionally, a series of one-way repeated measure ANOVAs were conducted to examine the magnitude of changes from baseline across the work interval in the dependent variables within each exercise condition in Chapters 4-8. In the event of significant effects ($P < 0.05$), follow-up Bonferroni adjusted post hoc tests were conducted to examine the location of mean differences. Standardised ES were used to detail the magnitude of the effect using the thresholds of: small (>0.2), moderate (>0.5), large (>0.8) and very large (>1.0) (Cohen, 1988). The alpha level was set at 0.05 for all analyses. Pearson's product-moment correlation coefficient was also used to examine the relationships between affect responses with other variables (i.e. PFC hemodynamics, during and post-exercise enjoyment, RPE and HR responses).

CHAPTER 4: Acute cardiorespiratory, perceptual and enjoyment responses to high-intensity interval exercise in adolescents

4.1 Abstract

Purpose: This study aimed to examine adolescents' acute cardiorespiratory and perceptual responses during HIIE and enjoyment responses following HIIE and work-matched CMIE. **Methods:** Fifty-four 12- to 15-year olds (27 boys) completed 8 x 1 minute cycling at 90 % PPO with 75-s recovery (90%HIIE) and at 90 % of the VT (CMIE). $\dot{V}O_2$, %$\dot{V}O_{2max}$, HR, %HR_{max} and RPE were collected during HIIE. Enjoyment was measured using the PACES following 90%HIIE and CMIE. **Results:** Boys elicited higher absolute $\dot{V}O_2$ during 90%HIIE work ($p<0.01$, ES>1.22) and recovery ($p<0.02$, ES>0.51) intervals but lower %$\dot{V}O_{2max}$ during 90%HIIE recovery intervals compared to girls ($p<0.01$, ES>0.67). No sex differences in HR and %HR_{max} were evident during 90%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 90%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 90%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). **Conclusions:** 90%HIIE elicits a maximal cardiorespiratory response in most adolescents. Greater enjoyment after 90%HIIE was due to elevated feelings of reward, excitement and success and may serve as a strategy to promote health in youth.

4.2 Introduction

Observational studies in children and adolescents have demonstrated that cardiometabolic risk factors are more closely associated with vigorous intensity PA than light or moderate intensity PA (Ruiz et al., 2006, Steele et al., 2009). Furthermore, recent studies have shown that only a small volume (<7 minutes) of vigorous intensity PA may be needed to promote health benefits in youth (Carson et al., 2014, Hay et al., 2012). Therefore, HIIE involving short repeated bouts of vigorous intensity PA, 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 (Logan et al., 2014, Costigan et al., 2015).

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, Thackray et al., 2016, Cockcroft et al., 2015). Despite evidence for this HIIE protocol to promote a myriad of health benefits in adolescents, little is known about the acute cardiorespiratory (i.e., HR and $\dot{V}O_2$ and 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 et al., 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., 2015b, Tschakert and Hofmann, 2013) and differ between males and females (Laurent et al., 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 and Batterham, 2015, Hardcastle et al., 2014). Paradoxically, enjoyment is reported to be higher after HIIE compared to CMIE in adolescents (Bond et al., 2015a, 2015b, 2015c). However, enjoyment following exercise was quantified using the modified 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 minute 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.

4.3 Methods

4.3.1 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.

4.3.2 Anthropometric measures

Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg. 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 et al. (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 and Udry, 1980).

4.3.3 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 VT (Barker et al., 2011).

4.3.4 High-intensity interval exercise and continuous moderate-intensity exercise protocols

The HIIE protocol consisted of a 3 minutes warm-up at 20 W, followed by 8 × 1 minute intervals at 90% of the PPO determined from the ramp test to exhaustion, interspersed with 75 s of recovery at 20 W, before a 2 minutes cool down at 20 W (90%HIIE). The CMIE protocol incorporated continuous moderate-intensity cycling at 90 % of VT. 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.

4.4 Measures

4.4.1 Gas exchange and heart rate

Expired gas samples during the cardiorespiratory fitness test and exercise protocols (90%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 VT was determined from the ramp test data and identified as the disproportionate increase in $\dot{V}CO_2$ relative to $\dot{V}O_2$. $\dot{V}O_{2max}$ was determined as the highest 10-s average in $\dot{V}O_2$ elicited either during the ramp or supramaximal test. 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.

4.4.2 Rating of perceived exertion

RPE was assessed using the 1–10 Pictorial Children's Effort Rating Table (PCERT; Yelling et al., 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.

4.4.3 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.

4.5 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 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. 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.

4.6 Results

The participants' descriptive characteristics are presented in Table 4.1. 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 90%HIIE exercise bout.

Table 4.1 Descriptive characteristic 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**
VT (L·min^{-1})	1.34 ± 0.31	1.10 ± 0.16	**0.01**	**0.96**
VT (%$\dot{V}O_{2\,max}$)	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; VT, ventilatory threshold.

4.6.1 Cardiorespiratory and rating of perceived exertion responses to high-intensity interval exercise

The mean interval by interval cardiorespiratory responses during the 90%HIIE protocol are illustrated in Figure 4.1. 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 90%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 90%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·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·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 90%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 90%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).

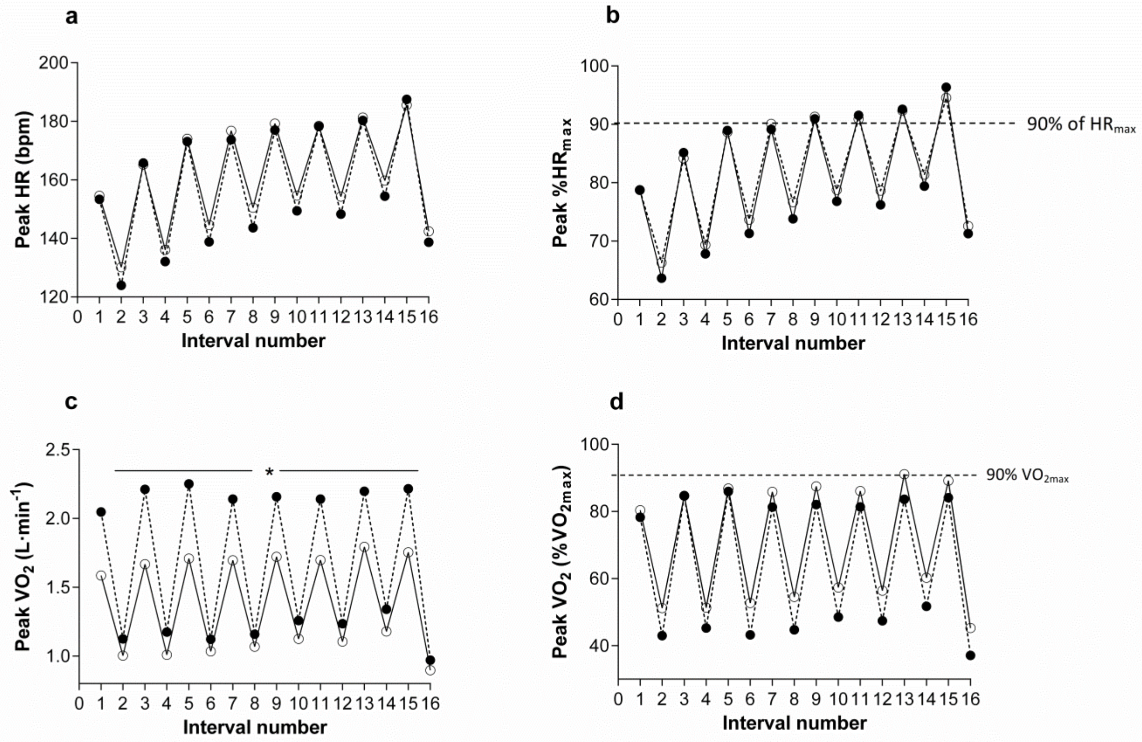

Figure 4.1 The mean peak heart rate (in beats per minute) (a), peak heart rate expressed as a percentage of maximal heart rate (b), peak oxygen uptake (in litres per minute) (c) and peak oxygen uptake expressed as a percentage of maximal oxygen uptake (d) during the work and recovery phases of the high-intensity interval exercise (90%HIIE) in boys (●) and girls (○). Where, the 90%HIIE 'interval' phases are 1,3,5,7,9,11,13,15 and the 90%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 4.2 presents the RPE data during the 90%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).

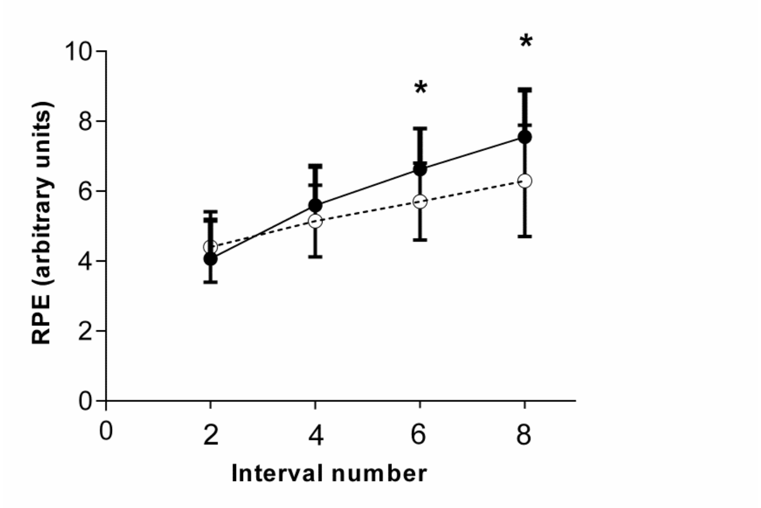

Figure 4.2 Mean and standard deviation for the rating of perceived exertion during 8x1 minute high-intensity interval exercise with 75 s of recovery in boys (●) and girls (○).*Significantly different between boys and girls. See text for details.

4.6.2 Exercise enjoyment

There was a significant main effect for condition (*P*=0.003) with the PACES score higher after 90%HIIE than CMIE in boys (90%HIIE=65 ± 8 vs. CMIE=58 ± 11, *P*=0.003, ES=0.73) and girls (90%HIIE=61 ± 6 vs. CMIE=58 ± 9, *P*=0.02, ES=0.39). Figure 4.3 illustrates the 16 single items PACES scores after 90%HIIE and CMIE for boys and girls separately. For boys and girls, a higher score after 90%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 90%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).

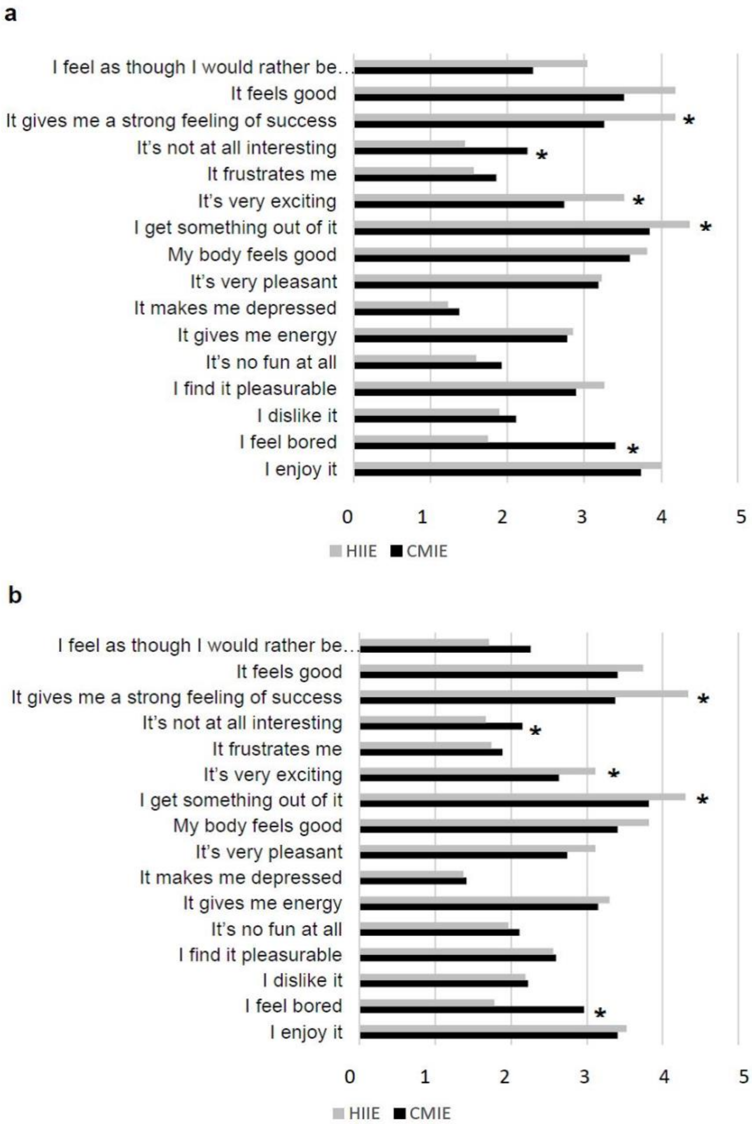

Figure 4.3 Mean (a) boys and (b) girls individual item score of the physical activity enjoyment scale (PACES) following high-intensity interval exercise (90%HIIE; grey) and continuous moderate-intensity exercise (CMIE; black). Item 1= “strongly disagree” to Item 5= “strongly agree”. *Significantly different from CMIE protocol. See text for details.

4.7 Discussion

The primary findings from this study are: 1) boys elicited higher absolute $\dot{V}O_2$ responses during the work and recovery 90%HIIE intervals, but elicited lower $\%\dot{V}O_{2max}$ during the 90%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 90%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 90%HIIE protocol; 4) boys elicited greater RPE during the later stages of the 90%HIIE protocol compared to girls; and 5) 90%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 90%HIIE.

In both sexes, the cut-off point of ≥90 % HR_{max} was attained following the fifth 90%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 90%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 et al. (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 90%HIIE protocol and did not attain $\dot{V}O_{2max}$. This finding is in agreement with the work of Tucker et al. (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 minute 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 minutes HIIE protocol when compared to the 16 x 1 minute protocol (~76–85 % $\dot{V}O_{2max}$). We therefore reason that the use of 1 minute duration work intervals for the 90%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 90%HIIE work and recovery intervals (see Figure 4.1), 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 90%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 minute running in adolescent boys and girls, respectively. However, although we found similar relative physiological responses between sexes when performing 90%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 and 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 90%HIIE protocol as boys were exercising at a greater power output during 90%HIIE.

It is well documented that the motivation to participate in exercise or PA 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 90%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 90%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 90%HIIE compared to 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 et al., 1990). Baron and Downey (2007) also report that increasing youth's perception of success in different PA may also increase feelings of enjoyment. Given that enjoyment to PA 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 90%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 90%HIIE compared to CMIE. Coupled with the greater enjoyment following 90%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 et al., 2006, Salmon et al., 2009). According to the SDT (Deci and 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 et al., 2017), 90%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 and Batterham, 2015, Hardcastle et al., 2014). Therefore, enjoyment responses during exercise alongside with affective (i.e. pleasure/displeasure feelings) evaluations are needed in future HIIE 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 et al.,

2009) and preference of exercise mode (Daley and Maynard, 2003). Another potential limitation is that enjoyment was quantified after, but not during, the exercise bouts.

4.8 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 90%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}). For example, physical education teachers may design an intermittent running/cycling exercise session by instructing the students to run/cycle in any direction within the wide area (e.g. school field and sport hall) for 1 minute (repeat for 8 times, work intervals) interspersed with 75 seconds of recovery). In order to achieve the high-intensity level, teachers may ask the students to find a pace that makes them perceive ‘just feeling a strain’ during the initial four repititions and a pace that makes them perceive ‘hard or very hard’ during the last four repititions based on the RPE scale. This sessions also can be aided by monitoring the HR responses of the students half way through the session (e.g. after the 4th repetition) and at the end of the session (e.g. after the 8th repetiton) to make sure that the students sufficiently comply with the prescribed exercise dose of HIIE (e.g. achieve >90%HR_{max}). A practical technique that can be used by teachers to monitor HR responses during the PE sessions is by taking the pulse rate at the radial (wrist) or carotid (neck) site of the body (Acevedo and Starks, 2011). Both RPE and HR have succesfully been used as an objective measure to monitor the intensity of HIIE in a school setting (Bond et al., 2017). However, the HIIE programme is not necessary limited to running/cycling exercise as other forms of HIIE, such as skipping, small sided games or circuit exercises, can be performed.

CHAPTER 5: Perceptual responses to high- and moderate-intensity interval exercise in adolescents

5.1 Abstract

Purpose: CHIE is proposed to evoke unpleasant sensations as predicted by the DMT, and may negatively impact on future exercise adherence. Previous studies support unpleasant sensations in affective responses during CHIE, but the affect experience during HIIE involving brief bursts of high-intensity exercise separated by low-intensity activity is poorly understood in adolescents. We examined the acute affective, enjoyment and perceived exertion responses to HIIE compared to MIIE in adolescents. **Methods**: Thirteen adolescent boys (mean ± SD; age 14.0 ± 0.5 years) performed two counterbalanced exercise conditions: 1) 90%HIIE: 8 x 1 minute work intervals at 90% MAS; and 2) MIIE: between 9-12 x 1 minute work intervals at 90% VT where the number of intervals performed were distance-matched to HIIE. HIIE and MIIE intervals were interspersed with 75 s active recovery at 4 $km \cdot h^{-1}$. Affect, enjoyment and RPE were recorded before, during and after exercise. **Results**: Affect responses declined in both conditions but the fall was greater in 90%HIIE than MIIE ($P<0.025$, ES=0.64 to 0.81). Affect remained positive at the end work-interval for both conditions (MIIE= 2.62 ± 1.50; HIIE= 1.15 ± 2.08 on feeling scale). No enjoyment differences were evident during 90%HIIE and MIIE ($P=0.32$), but 90%HIIE elicited greater post-exercise enjoyment compared to MIIE ($P=0.01$, ES=0.47). RPE was significantly higher during 90%HIIE than MIIE across all work-intervals (all $P<0.03$, ES>0.64). **Conclusions**: Despite elevated RPE, 90%HIIE did not elicit prominent unpleasant feelings as predicted by DMT and was associated with greater post-exercise enjoyment responses than MIIE. This study demonstrates the feasibility of the application of 90%HIIE as an alternative form of PA in adolescents.

5.2 Introduction

HIIE has been shown to improve cardiorespiratory fitness and cardiometabolic health in adolescents (Costigan et al., 2015). Given that low levels of PA in youth are evident (Department of Health, 2011), HIIE has emerged as a strategy to engage adolescents in PA. The application of HIIE in adolescents is contentious, however, with sceptics highlighting that the psychologically aversive nature and greater exertional stress of high-intensity exercise may lead to poor implementation and adherence (Biddle and Batterham, 2015). This contention is based on the DMT, which explains the relationship between affective responses and exercise intensity (Ekkekakis et al., 2005b). DMT predicts that in the moderate domain (intensities below the VT), there is low-to-moderate influence of cognitive factors (e.g. self-efficacy), and affective responses remain pleasurable. In the heavy domain (intensities from VT to maximal lactate steady state), cognitive factors have a strong influence, with interoceptive cues associated with the physiological strain of exercise (e.g. increased HR and ventilation) having a minimal influence. Thus, affective responses are likely to vary between individuals with some individuals interpreting the intensity as pleasurable, while others as an unpleasant feeling in the heavy domain. In the severe domain (intensities between maximal lactate steady state to the level of maximal exercise capacity or termed as high-intensity exercise), there is a predominance of interoceptive cues due to the increased contribution of anaerobic sources, whereas a physiological steady state can no longer be maintained and is associated with unpleasant feelings (Ekkekakis et al., 2005b). Research shows that affective responses are modulated not only by exercise intensity, but also by perceived exertion (Oliveira et al., 2015). Elucidating this information during HIIE is therefore important as affective evaluation during exercise may influence future attitudes towards PA behaviour in adolescents (Schneider et al., 2009).

Several studies in youth provide support for the DMT showing exercise performed above the VT during incremental and continuous type protocols has an affective response that is negative and unpleasant (Stych and Parfitt, 2011, Benjamin et al., 2012). Nonetheless, these evaluations were made during continuous or incremental exercise, which may not translate to HIIE involving brief bursts of high-intensity exercise separated by periods of light-intensity recovery exercise. Evidence from adults reveals that HIIE elicited more pleasurable feelings compared to CHIE but less pleasurable or similar than CMIE (Jung et al., 2014, Martinez et al., 2015). These findings show that low-intensity exercise performed during the HIIE recovery intervals may not hold negative feelings and high exertional stress (i.e. perceived exertion), when the high-intensity exercise is performed in brief bursts interspersed with periods of recovery. Whether HIIE is perceived as aversive by youth populations however, is currently unknown.

Previous studies have shown that adolescents report greater enjoyment following HIIE, than when they engage in CMIE exercise (Bond et al., 2015a, Bond et al., 2015b). However, enjoyment in previous adolescent HIIE studies was measured post-exercise, using the PACES. As post-exercise feelings may reflect a ‘rebound’ from the previous feeling stimulated during high-intensity exercise (Ekkekakis et al., 2005b), important dynamic changes during exercise (Bixby et al., 2001) may have been missed. Since adolescents prefer to engage in interval type exercise rather than continuous constant exercise regardless of exercise intensity (Barkley et al., 2009), this pattern of activity seems important in promoting adherence to exercise interventions. Furthermore, children and adolescents perform their habitual physical activity in an intermittent (i.e. interval) manner (Bailey et al., 1995), and there is strong evidence showing time spent performing moderate intensity PA and vigorous PA is related to health benefits in this population (Janssen and Leblanc, 2010). Therefore, it is crucial to compare enjoyment and affective responses between interval type protocols with different exercise intensities (e.g., moderate intensity vs. high intensity), both during and after exercise, in order to gain insight in terms of the feasibility of interval exercise in adolescent populations.

The purpose of the present study is to examine the acute affective, enjoyment and perceived exertion responses to HIIE and MIIE in adolescent boys. We also examined any potential relationship between enjoyment, RPE and physiological responses with the affect responses during HIIE and MIIE. We hypothesised that 1) affective responses will decrease more during HIIE than MIIE and would be less positive during HIIE, 2) enjoyment would be similar during both HIIE and MIIE but greater enjoyment would be apparent after HIIE, and 3) there will be a significant correlation for enjoyment, RPE and HR responses with the affective responses during HIIE but not in MIIE.

5.3 Methods

5.3.1 Participants

Fourteen 13 to 15 years old adolescent boys were recruited into the study using a convenience sampling approach, with results presented for thirteen boys, as one boy dropped out for personal reasons unrelated to this study. The size of the sample was based on the ability to detect a medium to large effect in the affective responses

(Martinez et al., 2015) for a 2 (condition) by 8 (interval) repeated measures ANOVA with an alpha of 0.05 and power of 0.8. This resulted in an indicative sample size of 8 or 16 participants to detect a moderate and large effect respectively. The study procedures were granted by the Sport and Health Sciences Ethics Committee, University of Exeter. Written assent from the participants and written informed consent from the parent/guardian were obtained.

5.3.2 Anthropometric measures

Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg using standard procedures. 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 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).

5.3.3 Experimental protocol

This study required three experimental sessions in the laboratory, separated by a minimum three-day rest period, 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 two experimental visits involving a running HIIE or MIIE protocol, the order of which was counterbalanced to control for any order effect. All exercise tests were performed using a motorised treadmill (Woodway PPS 55 Sport slate-belt treadmill, Woodway GmbH, Weil am Rhein, Germany).

5.3.4 Cardiorespiratory fitness

Participants were familiarised with walking and running on the treadmill before completing an incremental speed-based protocol and supramaximal test to establish $\dot{V}O_{2max}$ and the VT. Participants began a warm-up against a speed of 4.0 km·h^{-1} for 3 minutes, followed by running at the speed of 6.0 km·h^{-1} with 0.5 km·h^{-1} increments every 30 s until volitional exhaustion, before a 5 minutes cool down at 4.0 km·h^{-1}. Throughout the incremental test, the treadmill gradient was set at 1%. Immediately 5 minutes after the cool down, participants performed a supramaximal test to exhaustion at 100% of MAS obtained from the incremental test with the treadmill gradient set at 5%. The supramaximal test was used to confirm measurement of $\dot{V}O_{2max}$.

5.3.5 High-intensity interval exercise and moderate-intensity interval exercise protocols

Participants completed: 1) HIIE consisting of a 3 minutes warm-up at 4.0 km·h^{-1} followed by 8 x 1 minute work intervals at 90% MAS determined from the incremental test (90%HIIE); and 2) MIIE: between 9 - 12 x 1 minute work intervals at 90% VT, where the numbers of work intervals matched the distance performed during HIIE condition for each participant. HIIE and MIIE intervals were interspersed with 75 s active recovery at 4 km·h^{-1}. A 2 minutes cool down at 4.0 km·h^{-1} was provided after each condition.

5.4 Measures

5.4.1 Gas exchange and heart rate

Expired gas exchange and ventilation variables during the cardiorespiratory fitness test and exercise protocols (90%HIIE and MIIE) were measured 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 intervals. The VT was determined from the incremental test data using the ventilatory equivalents for $\dot{V}CO_2$ production and $\dot{V}O_2$. $\dot{V}O_{2max}$ was determined as the highest 10 s average in $\dot{V}O_2$ elicited either during the incremental or supramaximal test. HR_{max} was taken as the highest HR achieved during the incremental or supramaximal tests. The collection of gas exchange data during the exercise conditions in our study is to demonstrate the extent to which participants complied with the prescribed intensities which is in line with other studies in adolescents (Bond et al., 2015a, Bond et al., 2015b).

5.4.2 Affective responses

Affective valence (pleasure/displeasure) was measured using the FS (Hardy and Rejeski, 1989) in line with previous work in adolescents (Benjamin et al., 2012, Stych and Parfitt, 2011). Participants rated their current feelings on an 11-point bipolar scale ranging from +5 to -5, with anchors at zero ("Neutral") and at all odd integers, ranging from "Very Good" (+5) to "Very Bad" (-5). Activation levels were measured using the FAS. The FAS (Svebak and Murgatroyd, 1985) is a single-item measure of perceived activation, with participants asked to rate themselves on a 6-point scale ranging from 1 to 6, with anchors at 1 'low arousal' and 6 'high arousal'. Participants were given standardised instructions on how to use the scales and were asked to provide their FS and FAS responses at 5 minutes before the exercise protocol, 20 s before the end of the warm-up session, 20 s before the end of each work and recovery interval, immediately post-exercise and 20 minutes post-exercise. FS and FAS were also obtained at the end of every stage during the incremental test to exhaustion to familiarise our participants with the scales and to link the affective responses data during incremental test to prevailing research on affect and enjoyment in adolescents. All the scales were administered by the same researcher.

Affective responses were also assessed from the perspective of the circumplex model (Russell et al., 1989), using a combination of FS and FAS scales (Benjamin et al., 2012). 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).

5.4.3 Perceived enjoyment

Participants rated their enjoyment during the exercise conditions on a 7-point EES (Stanley and Cumming, 2010). Participants were asked to rate their enjoyment in response to the standardised instruction: “Use the following scale to indicate how much you are enjoying this exercise session”. Anchors were given at every integer, ranging from “Not at all” at 1 to “Extremely” at 7. The EES was recorded 20 s at the end of the warm-up session, work and recovery intervals and the cool down. Enjoyment immediately after and 20 minutes after 90%HIIE and MIIE was measured using the modified 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”). Total enjoyment was calculated by summing the 16 responses after seven items were reverse-scored. This procedure yielded a possible range of scores from 16 through to 80 with a higher score representing greater enjoyment.

5.4.4 Rating of perceived exertion

RPE was assessed using the 1–10 Pictorial Children’s OMNI scale (Utter et al., 2002). The OMNI has a range of numbers familiar to youth (1 to 10) and uses age appropriate verbal expressions as descriptors of exercise effort. Anchors are given at every integer, ranging from ‘not tired at all’ (0) to ‘very, very tired’ (10). The same verbal instructions for using the scale were given to all participants before undertaking the exercise protocols. RPE was assessed at 20 s before the end of the warm-up session, end of the each work and recovery intervals, and end of the cool down.

5.5 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 normality of distribution for the dependent variables. Data were analysed using a two-way repeated measure ANOVA to examine differences in affect, enjoyment and RPE between HIIE and MIIE over time (e.g. the work and recovery intervals). Due to the differences in the interval numbers between the 90%HIIE and MIIE conditions, the initial 7^{th} work (and 6^{th} recovery) intervals in both conditions were compared, but the end interval of work and recovery in MIIE were compared against the 8^{th} work interval (and 7^{th} recovery interval) in 90%HIIE. A series of one-way repeated measure ANOVA were conducted to examine differences in affect, enjoyment and RPE responses within either HIIE or MIIE. In the event of significant effects, follow-up pairwise comparisons were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using 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 and recovery intervals.

5.6 Results

The participants' descriptive characteristics are presented in Table 5.1. Based on the age and sex specific aerobic fitness threshold cut-offs for poor cardiometabolic health (Adegboye et al., 2011), two participants were deemed to have a low level of fitness. One participant was categorised as overweight according to the international cut-offs for BMI (Cole et al., 2000).

Table 5.1 Descriptive characteristics of the participants (n = 13)

	Mean ± SD	Min	Max
Age (y)	14.0 ± 0.5	13.1	15.0
Body mass (kg)	49.6 ± 13.7	34.8	80.3
Stature (m)	1.62 ± 0.11	1.47	1.85
BMI ($kg \cdot m^{-2}$)	18.6 ± 3.2	14.5	26.7
Body fat (%)	12.7 ± 6.4	7.6	31.8
HR_{max} (bpm)	197 ± 10	175	213
MAS ($km \cdot h^{-1}$)	15.3 ± 2.1	10.5	17.5
$\dot{V}O_2$ ($L \cdot min^{-1}$)	2.48 ± 0.52	1.79	3.63
$\dot{V}O_{2max}$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	50.9 ± 5.5	36.0	56.0
HR at VT (bpm)	163 ± 10	141	172
RPE at VT	3.9 ± 0.8	3	6
VT ($L \cdot min^{-1}$)	1.72 ± 0.33	1.25	2.44
VT (%$\dot{V}O_{2\,max}$)	69.9 ± 3.8	64.4	78.3

Values are reported as mean ± standard deviation. Abbreviations: BMI, body mass index; $\dot{V}O_{2max}$, maximal oxygen uptake; HR_{max}, maximal heart rate; %$\dot{V}O_{2max}$, percentage of maximal oxygen uptake; VT, ventilatory threshold; MAS, maximal aerobic speed.

5.6.1 Cardiorespiratory responses

The cardiorespiratory responses data from the exercise conditions are presented in Table 5.2. All participants successfully completed the 90%HIIE and MIIE conditions. 90%HIIE elicited higher absolute HR, percentage of maximal HR (%HR_{max}), absolute $\dot{V}O_2$ and percentage of maximal $\dot{V}O_2$ (%$\dot{V}O_{2max}$) for all work intervals than MIIE (all P<0.01).

Table 5.2 Cardiorespiratory responses to high-intensity interval exercise performed at 90% maximal aerobic speed and moderate-intensity interval exercise.

	90%HIIE	MIIE	*P*-value	ES
Speed ($km \cdot h^{-1}$)	13.8 ± 1.9	8.8 ± 0.9	**<0.01**	3.36
Average HR (bpm)	155 ± 26	125 ± 20	**<0.01**	1.29
Average % HRmax	77 ± 13	63 ± 10	**<0.01**	1.21
Peak HR (bpm)	177 ± 13	143 ± 17	**<0.01**	2.25
Peak %HRmax	88 ± 4	72 ± 7	**<0.01**	2.81
Average $\dot{V}O_2$ ($L \cdot min^{-1}$)	1.55 ± 0.48	1.12 ± 0.34	**<0.01**	1.03
Average $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	62 ± 19	44 ± 14	**<0.01**	1.08
Peak $\dot{V}O_2$ ($L \cdot min^{-1}$)	2.01 ± 0.45	1.46 ± 0.36	**<0.01**	1.35
Peak $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	82 ± 8	58 ± 5	**<0.01**	3.60

Values are reported as mean ± standard deviation, probability (*P*), and effect size (ES). Significant differences are shown in bold. 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 gas exchange.

5.6.2 Affective responses

Incremental test: FS showed a significant effect of time (*P*<0.01) during the ramp-incremental test to exhaustion. The FS significantly declined from minute 1 to the VT (3.77 ± 1.24 vs. 1.77 ± 1.30; *P*<0.01, ES= 1.57), from the VT to VT + 1 minute (1.77 ± 1.30 vs. 0.38 ± 1.81; *P*<0.01, ES= 0.88) and then from VT + 1 minute to the end of the incremental test (0.38 ± 1.81 vs. -1.62 ± 1.98; *P*=0.02, ES= 1.05). Based on the FS and running speed relationship during the incremental test, the FS score was predicted to be circa -0.2 and +2.7 during 90%HIIE and MIIE protocols respectively.

90%HIIE and MIIE conditions: FS responses during the 90%HIIE and MIIE conditions are illustrated in Figure 5.1 A. FS showed a significant condition by interval number interaction effect (*P*< 0.01). FS was significantly lower during 90%HIIE than MIIE at work interval 5 to the end work interval (*P*<0.025, ES= 0.64 to 0.81) and at recovery interval 5 to the end recovery interval (*P*<0.012, ES=0.70 to 0.86). FS declined during the work intervals in both 90%HIIE (*P*<0.01) and MIIE conditions (*P*=0.028). Specifically, FS significantly decreased from the pre 5 minutes level at work interval 1 to work interval 8 during 90%HIIE (*P*<0.01; ES= 0.49 to 1.49). In contrast, during MIIE the decrease from pre 5 minutes was significant at work-interval 2 to end work-interval (*P*<0.014; ES= 0.34 to 0.75). FS remained positive at the end work-interval in the MIIE condition (2.62 ± 1.50, where +2 represents the indicator between 'good' and 'fairly good') and the 90%HIIE condition (1.15 ± 2.08, where +1 represents the 'fairly good' indicator). There were no significant differences (all *P*>0.51) for FS between 90%HIIE and MIIE at pre 5 minutes, immediately and 20 minutes after exercise. Additionally, a total of 11 participants (85%) remained in a positive feelings (> 1 on FS) and two participants (15%) evoked a negative feeling at the end work interval in 90%HIIE (< -1 on FS). In contrast all participants (100%) remained in positive affective responses in MIIE (> 2 on FS).

Correlations between FS and HR during the 90%HIIE and MIIE conditions are illustrated in Figure 5.1 B. A strong negative relationship was observed between absolute HR and %HRmax (r= -0.81, all *P*= 0.02) and with FS during the work intervals of 90%HIIE. However, no significant correlations were observed between HR responses and the FS during 90%HIIE recovery intervals (r=-0.56, all *P*=0.06), and for the MIIE work and recovery intervals (all r<-0.64, *P*>0.06).

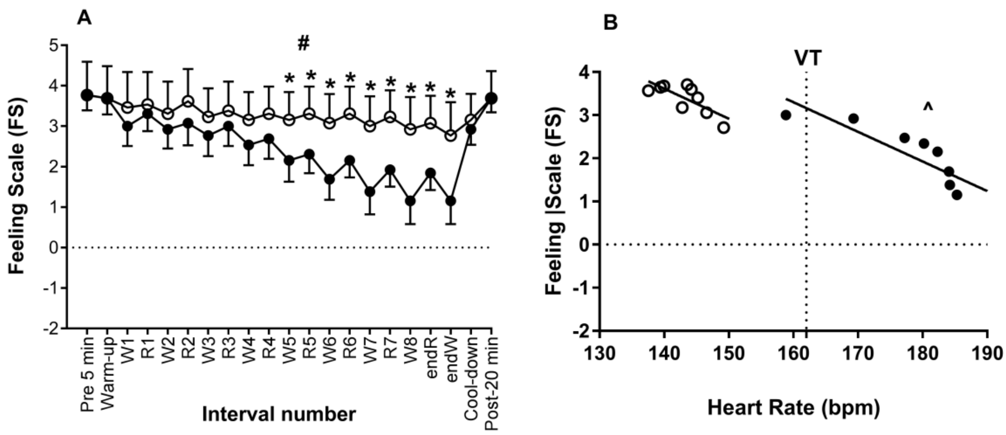

Figure 5.1 Feeling scale responses (A) and correlation analysis between feeling scale and heart rate (in beats per minute) (B) during the work and recovery phases of high-intensity interval exercise (90%HIIE; ●) and moderate-intensity interval exercise (MIIE; ○). Where, W= work interval, R= recovery interval, endW= work interval 8 in 90%HIIE and end work interval for MIIE, and endR= recovery interval 7 in 90%HIIE and end recovery interval for MIIE. *Significant difference between 90%HIIE and MIIE. #Significant condition by interval number. ^Significantly negative correlations Error bars are presented as standard deviation. See text for details.

FAS responses during 90%HIIE and MIIE are illustrated in Figure 5.2. FAS showed a significant condition by interval number interaction (P<0.01). FAS was significantly greater during 90%HIIE than MIIE at work interval 1 to end work interval (P<0.01; ES = 0.53 to 2.61) and at recovery interval 3 to end recovery interval (P<0.02; ES = 0.53 to 1.00). FAS increased during the work intervals in both exercise conditions (all P<0.01). Specifically, the increase from the pre 5 minutes level was significant at work interval 1 to end work-interval for 90%HIIE (P<0.01; ES= 2.03 to 5.44) and MIIE (P<0.01; ES= 0.78 to 1.37). There were no significant differences (all P>0.07) between exercise conditions for FAS at pre 5 minutes, immediately and 20 minutes after exercise.

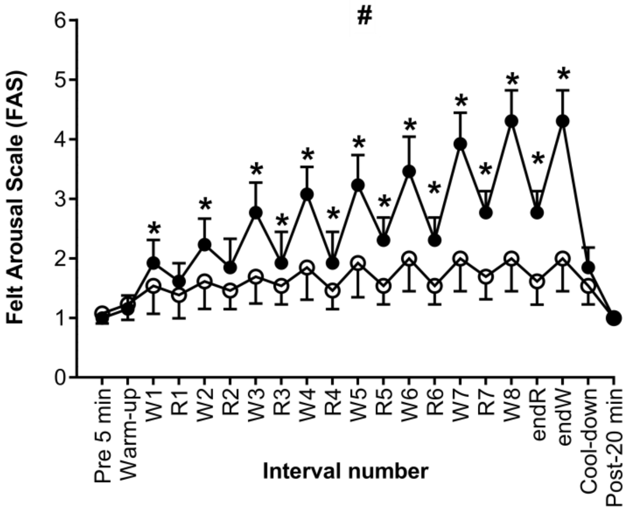

Figure 5.2 Felt arousal scale responses during the work and recovery phases of high-intensity interval exercise (90%HIIE; ●) and moderate-intensity interval exercise (MIIE; ○). Where, W= work interval, R= recovery interval, endW= work interval 8 in 90%HIIE and end work interval for MIIE, and endR= recovery interval 7 in 90%HIIE and end recovery interval for MIIE. *Significant difference between 90%HIIE and MIIE. #Significant condition by interval number. Error bars are presented as standard deviation. See text for details.

Affective responses (valence and activation) during the work and recovery intervals for 90%HIIE and MIIE were plotted onto a circumplex model (see Figures 5.3 A and B). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant for the 90%HIIE work intervals, but affective responses remained in the unactivated/pleasant quadrant for the 90%HIIE recovery intervals. In contrast, during MIIE, the affective responses remained in the unactivated/pleasant quadrant for the work and recovery intervals.

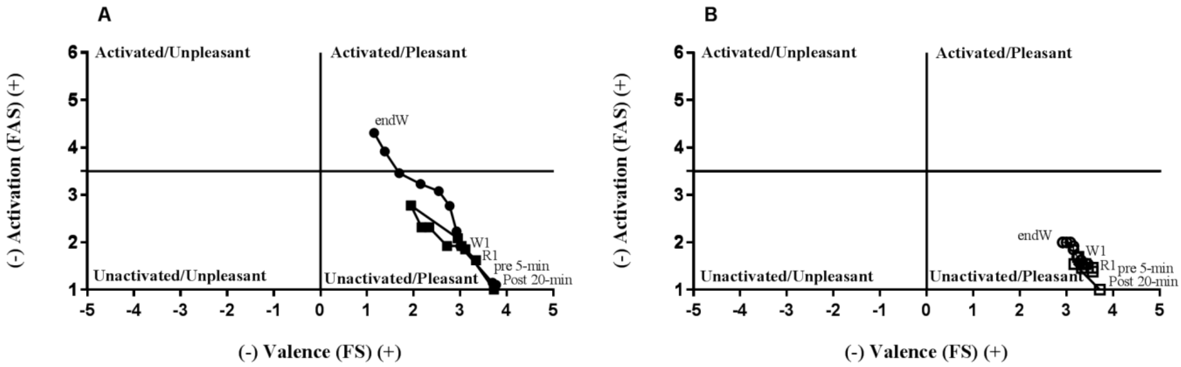

Figure 5.3 Valence (Feeling scale) and activation (Felt arousal scale) during the work and recovery interval of high-intensity interval exercise (90%HIIE) (A) and moderate-intensity interval exercise (MIIE) (B) plotted onto the circumplex model. 90%HIIE work interval (●) and recovery interval (■); MIIE work interval (○) and recovery interval (□). Where, W= work interval, R= recovery interval and endW= work interval 8 in HIIE and end work interval for MIIE. See text for details.

5.6.3 Exercise enjoyment responses

The enjoyment responses during 90%HIIE and MIIE are illustrated in Figure 5.4 A. EES only showed a significant main effect for interval number (*P*=0.001). EES declined during the work intervals for both 90%HIIE (*P*=0.001) and MIIE (*P*=0.04). In both conditions, the decline from warm-up was significant from work-interval 5 to the end work-interval (all *P*<0.006: 90%HIIE; ES=0.39 to 0.45; MIIE, ES=0.33 to 0.58). There was a strong positive correlation between ESS and the FS responses for 90%HIIE (*r*= 0.97, *P*<0.01) and MIIE (*r*= 0.86, *P*= 0.03,) as illustrated in Figure 5.4 B.

PACES showed a significant condition by time interaction (*P*=0.007). PACES was significantly higher immediately and post-20 minutes of 90%HIIE than MIIE (68 ± 6 vs. 64 ± 7, *P*=0.01, ES=0.47; 69 ± 5 vs. 61 ± 9, *P*=0.01, ES=1.10, respectively). PACES declined 20 minutes after MIIE (*P*=0.03, ES=0.34) but remained stable 20 minutes after 90%HIIE (*P*=0.23, ES=0.19). A higher score immediately and post-20 minutes after 90%HIIE compared to MIIE was found for PACES items “It’s very exciting” (all $P<0.02$, ES>0.68) and “It gives me a strong feeling of success” ($p<0.04$, ES>1.10). In contrast, there was a higher score immediately and post-20 minutes after MIIE compared to 90%HIIE for the item “I feel bored” ($p<0.08$, ES>0.91). There were no significant correlations between PACES and the FS responses during 90%HIIE (all r< 0.52, all P> 0.068) and MIIE (all r< 0.62, all P> 0.073).

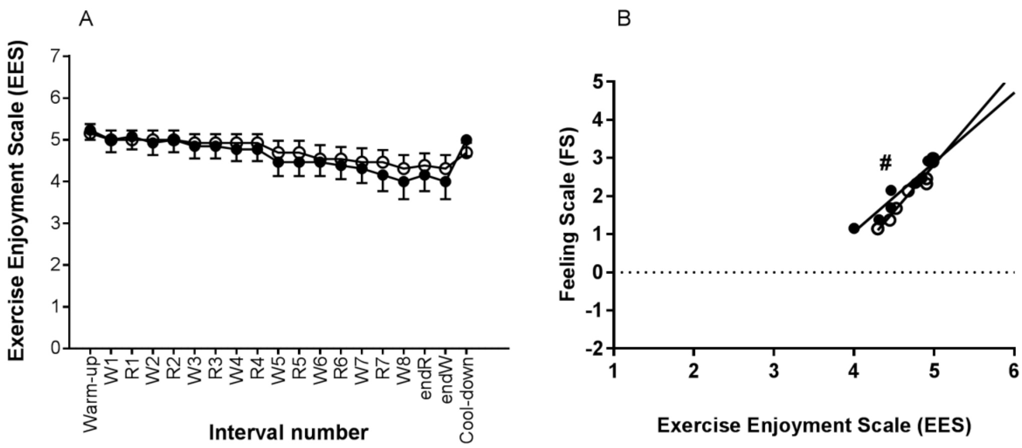

Figure 5.4 Exercise enjoyment responses (A) and correlation analysis between exercise enjoyment scale and feeling scale (B) during the work and recovery phases of high-intensity interval exercise (90%HIIE; ●) and moderate-intensity interval exercise (MIIE; ○). Where, W= work interval, R= recovery interval, endW= work interval 8 in 90%HIIE and end work interval for MIIE, and endR= recovery interval 7 in 90%HIIE and end recovery interval for MIIE. #Significantly positive correlations. Error bars are presented as standard deviation. See text for details.

5.6.4 Rating of perceived exertion responses

The RPE responses during 90%HIIE and MIIE are illustrated in Figure 5.5 A. RPE showed a significant condition by interval number interaction ($P<0.01$). RPE was significantly higher during 90%HIIE than MIIE for all work intervals (all $P<0.03$, ES=0.64 to 2.27). RPE increased during the work interval in both conditions

(*P*<0.01). During 90%HIIE, the increase in RPE from warm-up was significant at work-interval 1 to work interval 8 (*P*<0.01, ES=1.61 to 5.44), whereas during MIIE, the increase was significant at work interval 1 to work interval 5 (*P*< 0.01, ES= 1.10 to 2.07), whereafter RPE remained stable to the end work interval (all *P*>0.34, ES= 2.40 to 2.47). There was a strong negative correlation between RPE and FS responses during 90%HIIE (r=-0.97, *P*<0.01) but no significant correlation was present during MIIE (r=-0.66, *P*=0.06) as illustrated in Figure 5.5 B.

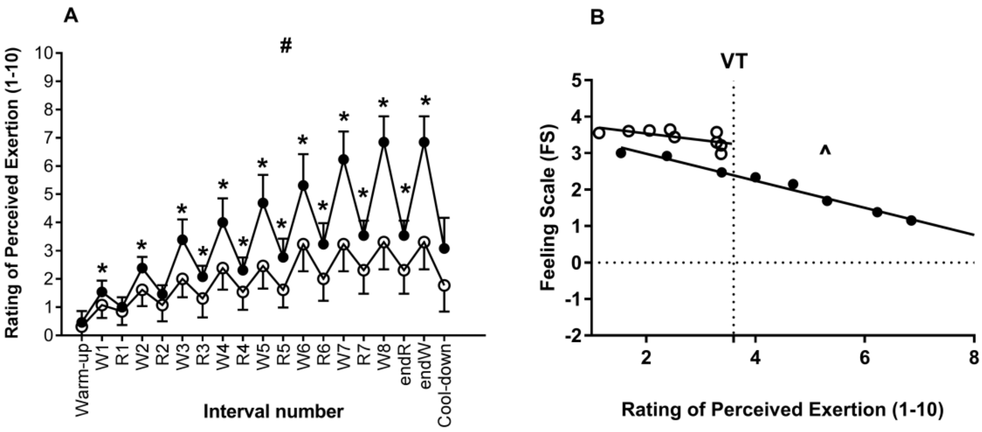

Figure 5.5 Rating of perceived exertion responses (A) and correlation analysis between rating of perceived exertion and feeling scale (B) during the work and recovery phases of the high-intensity interval exercise (90%HIIE; ●) and moderate-intensity interval exercise (MIIE; ○). Where, W= work interval, R= recovery interval, endW= work interval 8 in 90%HIIE and end work interval for MIIE, and endR= recovery interval 7 in 90%HIIE and end recovery interval for MIIE. *Significant difference between 90%HIIE and MIIE. #Significant condition by interval number. ^Significantly negative correlations. Error bars are presented as standard deviation. See text for details.

5.7 Discussion

The current study presents novel data on the affective, enjoyment and perceived exertion responses during 90%HIIE and MIIE in adolescent boys. The key findings from this study are: 1) 90%HIIE elicited a greater decline in affective valence than MIIE, but remained positive at the end work interval. A total of 85% of the participants remained in a positive feeling and 15% of the participants evoked a negative feeling at the end work interval in 90%HIIE. In contrast 100% of the participants remained in positive affective responses in MIIE; 2) no significant differences between 90%HIIE and MIIE were found for enjoyment responses during exercise, but 90%HIIE elicited greater enjoyment immediately after and 20 minutes post exercise compared to MIIE. Furthermore, enjoyment responses declined 20 minutes after MIIE but not for 90%HIIE; 3) affect and HR responses were significantly negatively correlated during 90%HIIE work intervals, but not during 90%HIIE recovery intervals and MIIE work and recovery intervals; 4) affect and enjoyment responses during exercise were positively correlated during both 90%HIIE and MIIE; and 5) affect and RPE responses were negatively correlated during 90%HIIE work intervals, but not during MIIE work intervals.

Previous affective responses studies in adolescents revealed that exercise at an intensity above the VT brings about a significant decline in affective valence, with scores below zero (e.g., -1.7 ± 2.8 of FS score) observed at the end of incremental exercise to exhaustion (Benjamin et al., 2012, Stych and Parfitt, 2011). Our FS responses during and at the end of the ramp incremental test to exhaustion demonstrate similar findings (i.e., -1.6 ± 1.9 of FS score) and are consistent with previous work in adolescents and the DMT. In our study, we used the speed during 90%HIIE and MIIE to predict the potential affect responses during these conditions according to the FS score elicited during the incremental test. Based on this, the FS score was predicted to be ~ -0.2 during 90%HIIE and ~ +2.7 during MIIE. We found that the overall mean scores for FS during MIIE work interval (i.e., 3.1 ± 0.23) was similar to prediction score, but were higher during the 90%HIIE work intervals (i.e., 2.1 ± 0.76). Our findings are consistent with previous adult studies that show positive affect responses during HIIE, but slightly lower affect responses than CMIE in sedentary and overweight adults (Jung et al., 2014, Martinez et al., 2015). We also found that affect responses were greater during recovery intervals compared to work intervals in both conditions (overall mean recovery: 90%HIIE, 2.6 ± 0.47; MIIE, 3.3 ± 0.05). Therefore, our data indicate that the recovery intervals during 90%HIIE have an influence on preserving the decline in FS. This is in line with the DMT, which predicts that a pleasurable feeling can occur during rest periods after an unpleasant stimulus or stress generated during work stimulus (Ekkekakis et al., 2005b).

The DMT postulates that during high-intensity exercise, physiological factors (e.g. HR) have a strong influence on the affective responses. These factors show that the changes in affective responses during HIIE work and the recovery intervals are likely to be mediated by the physiological responses produced during these periods. Interestingly, we found a significant negative correlation between affect and HR responses during 90%HIIE work intervals but not during 90%HIIE recovery intervals and MIIE work and recovery intervals. According to the DMT (Ekkekakis et al., 2005b), affective responses to exercise are regulated in a brain area, namely the PFC and the subcortical part. During high-intensity exercise, the functional capacity of the PFC becomes challenged by the intensified interoceptive cues (i.e. increased HR). This may induce deregulation in the PFC, resulting in a decreased (i.e. less positive/more negative) affective response mainly driven by the subcortical part (i.e. the amygdala). Although such mechanistic pathways are not exmained in the present study, it may be speculated that deregulation in the PFC might occur during 90%HIIE work intervals, due to intensified HR responses (peak HR corresponding to

88% HR_{max}), compared to lower HR responses during MIIE work intervals (peak HR corresponding to 72% HR_{max}). This deregulation may also explain the greater reductions in affective valence during 90%HIIE, compared to MIIE (see Figure 5.1), which is also consistent with previous research comparing HIIE to CMIE in adults (Decker and Ekkekakis, 2016, Jung et al., 2014). It has been reported that adolescents, in particular, reflect negative physiological cues, such as pains and aches, with a decline in their affect experience during high-intensity exercise (Stych and Parfitt, 2011). We speculate that the physiological variables associated with metabolic strain (i.e. HR, ventilation rate) exhibit a continuous upward "drift", which is in line with reported increases in HR during HIIE work intervals (Malik et al., 2017), marking an increase in the body's physiological and perceptual stress (see Figure 5.5), potentially leading to pain and a burning sensation during 90%HIIE, compared to MIIE.

We observed no significant differences between 90%HIIE and MIIE for the FS score during the initial five work intervals, which may indicate that the recovery intervals preserved the unpleasant feelings of 90%HIIE for about half of the total exercise bout. This finding is consistent with an adult-based study, which showed a similar affective response during the initial three work intervals of HIIE (Frazao et al., 2016). We also found an increase in activation (measured by FAS) responses from work interval one to the end interval, accompanied by a decrease in affective valence in both conditions, which is in line with previous studies in youth involving incremental exercise to exhaustion (Sheppard and Parfitt, 2008b, Benjamin et al., 2012). We plotted valence and activation responses to a circumplex model (Russell et al., 1989) to differentiate the dynamic changes occuring during 90%HIIE and MIIE. During 90%HIIE, affective responses moved from the unactivated pleasant quadrant (i.e.

evokes a sense of calmness and relaxation) and ended in the pleasant-activated quadrant (i.e. evokes a sense of excitement, enthusiasm, and happiness). However, affective responses remained in the unactivated pleasant quadrant during MIIE (see Figure 5.3). Our finding shows that the lack of activation (e.g. less excitement) may be a function of the overall exercise intensity of the MIIE trial being relatively easy and not too challenging. According to Rose and Parfitt (2007), a positive affective response can be achieved if an individual perceives they have the ability to complete an exercise session when they are comfortably challenged, which may drive feelings of excitement and enjoyment (Baron and Downey, 2007). It therefore appears that our participants perceived 90%HIIE protocol to be more challenging and at the same time have ability to cope with the prescribe exercise intensity and complete the 90%HIIE protocol, which in turn led to increased feelings of excitement compared to MIIE.

We observed a small to medium reduction in enjoyment responses measured by EES during both 90%HIIE (ES=0.39 to 0.45) and MIIE (ES=0.33 to 0.58) after the 5th work interval, indicating that enjoyment responses were maintained over initial ~ 50% of the total work for both conditions. The same finding was previously observed by Martinez et al. (2015), who reported a small decline in EES near the end of the work interval of HIIE with shorter intervals (i.e. 30 s and 60 s) in overweight adults. These authors also suggest that the pattern of enjoyment responses is similar to affective responses during HIIE work interval. Interestingly, we found a strong positive correlation between enjoyment and affective responses during exercise in both conditions. Raedeke (2007) suggest that enjoyment responses were positively related to positive affect but unrelated to negative affect. Our data seems to support this observation, as both conditions elicited positive affective responses to the interval exercise. The present study is the first to evidence the enjoyment responses during exercise conditions, by using a single-item scale of EES in adolescents. However, EES has only been used in a few studies in adults (Martinez et al., 2015, Stanley and Cumming, 2010), and there is a possibility of erroneous responses (due to confusion or carelessness), due to the single-item measure, as compared to the multi-item measure of the same construct (e.g. PACES). Therefore, the enjoyment responses during exercise conditions that are presented in this study may be speculative.

In contrast to the enjoyment during exercise, we observed greater enjoyment, as measured by PACES, after 90%HIIE compared to MIIE. This is consistent with previous HIIE studies on adolescents that contrasted against work-matched CMIE (Bond et al., 2015b). Interestingly we found no significant correlations between affect responses and post-enjoyment in both exercise conditions, which is contrary with enjoyment responses during exercise. This difference may be due to the measurement tools used to identify enjoyment responses during (single item of EES) and after (PACES questionnaire) exercise. However, our finding of no significant relationship between affect and post-exercise enjoyment could be explained via distinctions between affect and enjoyment (Russell and Feldman Barrett, 1999). Specifically, affect only represents general feelings that are independent of the cognitive process, whereas enjoyment (emotional experience) is elicited following a cognitive appraisal process during which a stimulus (i.e. exercise intensity) is recognised as either beneficial or detrimental to the person. In this present study, we found that 90%HIIE elicited a strong feeling of success and a feeling of excitement immediately and after 20 minutes of exercise based on the individual PACES items which in line with our previous study that examined individual items on PACES scale following HIIE in adolescent boys and girls (Malik et al., 2017). In contrast, participants rated a higher score in the item ‘I feel bored’ immediately and after 20 minutes of MIIE. This may explain the decline in PACES score following 20 minutes of MIIE but not in 90%HIIE. Research findings show that an increase in enjoyment could lead to an increase in PA as feeling of enjoyment serves an immediate reward for being physically active (Dishman et al., 2005). Therefore, our findings provide foundations to highlight that enjoyment and affective responses during 90%HIIE protocol could possibly improve PA levels in contrast to MIIE while the retention to PA is a recurrent challenge.

We found an increase in RPE during the 90%HIIE work intervals but an opposite pattern was observed for the affective responses, which are consistent with previous HIIE studies in adults (Oliveira et al., 2015, Frazao et al., 2016). Our study also revealed a strong negative correlation between RPE and the affective response to 90%HIIE but not during MIIE. This is consistent with the study by Acevedo et al. (1994) who revealed that RPE and affect responses were correlated during CHIE but not during CMIE in well trained adults. This finding can be explained through the parallel processing model proposed by Leventhal and Everhart (1979). The parallel processing model proposes that an increase in an individual’s exertional responses (i.e. fatigue and pain) is reflected by an increase in physiological cues (e.g. HR). Thus, during 90%HIIE, when physiological cues become predominant during exercise, exertional responses will occupy the limited capacity of focal awareness (the sensory data to which one chooses to attend) to the brain area (i.e. PFC) which might not occur during MIIE. Also our data strengthens the idea proposed by Oliveira et al. (2015) which suggests affective responses are not only mediators of the exercise intensity, but also 'how' the individuals perceive the intensity that they are performing.

There are several limitations that should be acknowledged. This study is limited to the recruitment of healthy adolescent boys with a small sample size. Therefore, data cannot be generalised to more diverse groups (e.g., adolescent girls, different fitness level). Despite this limitation, the exercise protocols adopted in this study have already been shown to be feasible and enjoyable for both adolescent boys and girls (Bond et al., 2015a, Bond et al., 2015b). Moreover, no sex differences were identified in previous studies examining affective responses in adolescents (Stych and Parfitt, 2011, Benjamin et al., 2012). Future research examining affect and enjoyment responses, however, need to include both sexes to investigate whether there are any potential sex differences. This study utilised a facemask during the exercise conditions for the collection of gas exchange data, which will not be representative of the 'real world' setting and may influence the exercise perceptual responses. However, our previous work has shown that a similar external work-rate (i.e. power output) for HIIE does not adequately describe the internal work demand (e.g. HR and $\dot{V}O_2$) during the exercise (Malik et al., 2017). Given this observation, it is important to collect the gas exchange and HR data during the experimental trials. Furthermore to limit the effect of the facemask, its use was standardised across all the experimental trials to avoid any method biases (e.g. any possible effects of wearing [or not] the facemask on the perceptual responses to exercise). This methodological approach was also in line with a previous study examining affective responses to incremental exercise in youth (Benjamin et al., 2012). Another limitation is that this study did not measure the PA level of the participants. Moreover, our participants had a high cardiorespiratory fitness level (~ 50 $mL \cdot min^{-1} \cdot kg^{-1}$). Given that previous research has highlighted that affective responses during exercise are influenced by the previous activity history of participants (Stych and Parfitt, 2011, Sheppard and Parfitt, 2008b), future research may benefit from an attempt to recruit participants with a range of fitness levels to evaluate any differences in affect and enjoyment responses during HIIE. Also, research should examine the role of affect and enjoyment during HIIE with a different protocol as multiple numbers of HIIE protocols can be prescribed by altering the intensity and duration of the work and recovery intervals, which in turn may alter the intensity-affect relationship.

5.8 Practical Implications

This study explores adolescent boys' affective, enjoyment and exertional responses during 90%HIIE and MIIE protocols. Given that the 90%HIIE protocol used in our study has been shown to produce health benefits in previous adolescents based studies (Bond et al., 2015a, Bond et al., 2015b), this type of HIIE protocol could be an effective health improvement strategy, which appeals to adolescents due to the positive affect and greater post-enjoyment responses compared to MIIE. The HR responses (e.g. peak HR and average HR during work interval) collected in our study could be used to further aid intensity prescription for non-laboratory based HIIE protocols (Taylor et al., 2015), such as those conducted in schools (Weston et al., 2016), where the need for inexpensive and practical exercise intensity monitoring tools is essential. We also recommend the practical use of simple tools of psychometric measurement (i.e. FS, RPE, and EES scale) to prescribe and monitor HIIE. Thus, combining HR and psychometric tools may offer useful strategies to monitor HIIE by teachers or exercise professionals. For example, a similar programme can be designed by teachers or educators as outlined in Chapter 4.

Students can be asked to run in any direction within a wide area (e.g. school field or sports hall) for 1 minute (repeat for 8 times, work interval) interspersed with 1 minute of walking (recovery interval). Instead of using RPE and HR responses to monitor the high-intensity work intervals, teachers may ask the students to maintain the running pace that could elicit at least a ‘good’ feeling score (between +2 to +4 on FS) for the initial four repititions and a pace that makes them feel ‘fairly good’ (between +1 to +2 on FS) for the last four repititions. These guidelines may allow the students to self-select an intensity indicative of HIIE while maintaining pleasurable feelings across the exercise bout. Indeed, a previous study in adults has shown that FS can be used in an exercise programme to regulate exercise intensity (Parfitt et al., 2012). Nevertheless, RPE and HR responses could also be used at any specific time to confirm that the students comply with the prescribed HIIE dose. Specifically, to achieve high-intensity levels, the running pace should generate RPE scores between 2-4 (‘little tired’ to ‘getting more tired’) with the HR responses corresponding to ~82%-86% HR_{max} for the initial four repititions, and RPE scores between 6-7 (‘tired’) with the HR responses corresponding to ~90%-97% HR_{max}, during the last four repetitions. Likewise, as highlighted in Chapter 4, a HIIE protocol is not necessarily restricted to running, as many permutations can be formed by manipulating the intensity and duration of the work and recovery bouts and the exercise modality (e.g. cycling, jumping jack, dance, skipping and boxing).

5.9 Conclusion

Our data show that 90%HIIE can negate the prominent negative affective responses predicted by DMT, as has been shown in incremental tests and continuous high-exercise protocols in adolescents (Benjamin et al., 2012, Stych and Parfitt, 2011).

Despite 90%HIIE resulting in a greater decline and lower affective responses compared to MIIE, which fit the expected pattern of responses by DMT, the low-intensity exercise performed during recovery may not hold prominent negative emotions during HIIE. Therefore, the DMT may require modification, in order to more adequately consider the influence of interval exercise on affective responses to exercise. Our study also shows that HR, RPE and enjoyment responses are significantly correlated to the affect responses changes during 90%HIIE. Despite greater cardiorespiratory and perceived exertion responses during 90%HIIE than MIIE, participants reported 90%HIIE to be pleasant and more enjoyable than MIIE. Therefore, our findings show that HIIE does not elicit a psychologically aversive nature as proposed by others (Biddle and Batterham, 2015, Saanijoki et al., 2015) and demonstrates the feasibility of the application of HIIE as an alternative form of exercise in adolescents.

CHAPTER 6: Perceptual and cardiorespiratory responses to high-intensity interval exercise in adolescents: does work intensity matter?

6.1 Abstract

Purpose: 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. **Methods**: 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% PPO separated by 75 seconds recovery at 20 W. Affect, enjoyment and RPE were recorded before, during, and after HIIE. HR and oxygen uptake were collected during HIIE. **Results**: 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 FS). 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%). **Conclusions**: 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 health benefits.

6.2 Introduction

Given that short bouts of vigorous intensity PA may drive numerous health benefits (Carson et al., 2014, Hay et al., 2012, Barker et al., 2018) and the intermittent nature of habitual PA in youth (Bailey et al., 1995), HIIE training has been proposed as a strategy to engage adolescents 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 VT up to the level of maximal exercise capacity) exercise intensity domains (Malik et al., 2017, Bond 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 DMT explains the exercise intensity-affect relationship during exercise (Ekkekakis et al., 2005b) 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 remain homogenously positive (i.e. pleasurable). In the heavy exercise intensity domain (exercise performed between the VT to the RCP), there is strong dominance of cognitive factors, with interoceptive cues associated with the physiological strain of exercise (e.g. increased HR) having a minimal influence. Hence, affective responses are likely to vary between individuals with some individuals may report changes toward pleasure, while others may report as an unpleasant. In the severe exercise intensity domain (exercise performed above the RCP), there is a strong dominance of interoceptive cues due to the increased dependent of anaerobic sources, whereas a physiological steady state can no longer be maintained, and is associated with homogenously negative affect (i.e. feelings of displeasure) (Ekkekakis et al., 2005b).

Previous studies in adolescents have supported the observation of negative affective responses during continuous and incremental exercise when it 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 minute performed at 90% PPO separated with 75 s active recovery) generates greater enjoyment following HIIE compared to CMIE or MIIE and does not have prominent negative affective responses (Malik et al., 2017, Malik et al., 2018b). The authors (Malik et al., 2018b) 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% PPO), yet a variety of HIIE work intensities (e.g. 70% to 100% of maximal exercise capacities) have been shown to be effective in facilitating health benefits in children and adolescents (Bond et al., 2017). It has been demonstrated in adolescent that HIIE cycling performed at decreasing work intensity (100% to 70% PPO) elicited more pleasurable feelings in affective responses than HIIE cycling performed at increasing work intensity (70% to 100% PPO) (Malik et al., 2018a), 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., 2005b). 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 $\dot{V}O_2$) and perceived exertion (i.e. 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., 2018b). 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 (Taylor et al., 2015, Schneider et al., 2009).

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% PPO) during an 8 × 1 minute 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 the work intensity, with HIIE at 100% PPO eliciting less pleasurable feelings than HIIE at 70% and 85% PPO.

6.3 Methods

6.3.1 Participants

Sixteen 11-13-year-old adolescents (8 boys) volunteered to take part in the study. 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., 2018b) 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).

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

6.3.3 Anthropometric, maturation offset and physical activity measures

Body mass and stature were measured to the nearest 0.1 kg and 0.1 cm, respectively. 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 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 maturers participants were defined as the offset score <-1 year, typical matures participants were defined as the offset score between -1 to 1 year and late maturers 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 MVPA using a cut-off point of ≥1140 counts per minute previously validated in youth (Phillips et al., 2013).

6.3.4 Cardiorespiratory fitness

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

6.3.5 High-intensity interval exercise protocols

Participants performed the HIIE protocols consisting of a 3 minutes warm-up at 20 W followed by 8 x 1 minute work intervals at either 70% (70%HIIE), 85% (85%HIIE) or 100% (100%HIIE) of the PPO determined from the ramp test, interspersed with 75 s active recovery at 20 W. A 2 minutes 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 minutes 15 s).

6.4 Experimental Measures

6.4.1 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 $\dot{V}CO_2$ production and $\dot{V}O_2$. $\dot{V}O_{2max}$ and 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).

6.4.2 Affective, enjoyment and rating of perceived exertion responses

A detailed explanation of the affect, enjoyment and RPE measurements is presented in Chapter 5.

6.4.3 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 minutes 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 minutes 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 our participants with the scales. All the scales were administered by the same researcher.

6.5 Statistical analyses

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 ANOVA to examine sex differences in affect, enjoyment, RPE and cardiorespiratory data between HIIE the protocols (70%, 85% and 100% PPO) 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 interval in affect, enjoyment and RPE responses within each HIIE protocols. 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 test were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using 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.

6.6 Results

The participants' descriptive characteristics are presented in Table 6.1. 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 an earlier maturers (>+1 of maturation offset). The remaining of nine participants were categorised as maturers on time. One boy was achieving the recommended guideline of 60 minutes 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.

Table 6.1 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*	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).

6.6.1 Cardiorespiratory responses

The cardiorespiratory data from the exercise conditions for boys and girls are presented in Table 6.2. 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} 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.

Table 6.2 Cardiorespiratory responses to high-intensity interval exercise 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 $\dot{V}O_2$ ($L{\cdot}min^{-1}$)	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 $\dot{V}O_2$ ($L{\cdot}min^{-1}$)	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 gas exchange.

*Significant difference between 70%HIIE (*P*< 0.01).

#Significant difference between 85%HIIE (*P*< 0.01).

^Significant difference between 100%HIIE (*P*< 0.01).

6.6.2 Affective responses

FS responses during the three HIIE conditions are illustrated in Figure 6.1. 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 interval 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 minutes pre at work interval 6 to 8 (*P*<0.04; ES=1.03 to 1.27) and at recovery interval 6 to 7 (*P*<0.029; ES=0.70 to 0.83). During 85%HIIE the decrease from 5 minutes 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 minutes 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 6.2. 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).

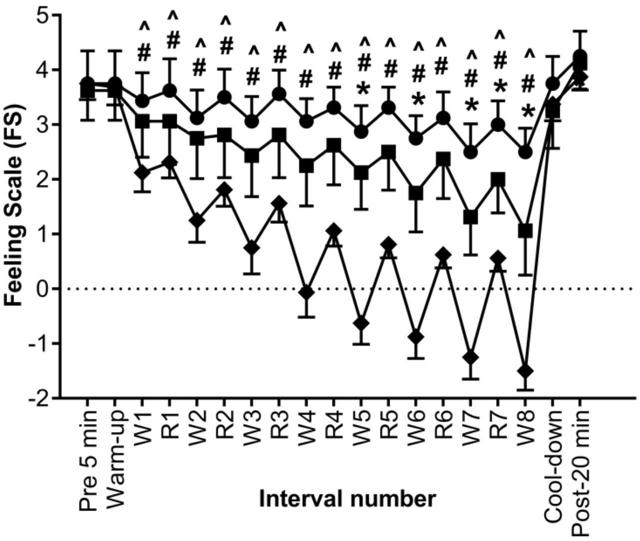

Figure 6.1 Feeling Scale during the work and recovery phases of high-intensity interval exercise performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Where, W= work interval and R= recovery interval. *Significant difference between 70%HIIE and 85%HIIE. #Significant difference between 70%HIIE and 100%HIIE. ^Significant difference between 85%HIIE and 100%HIIE.*Significant difference between 70%HIIE and 85%HIIE. Error bars are presented as standard deviation. See text for details.

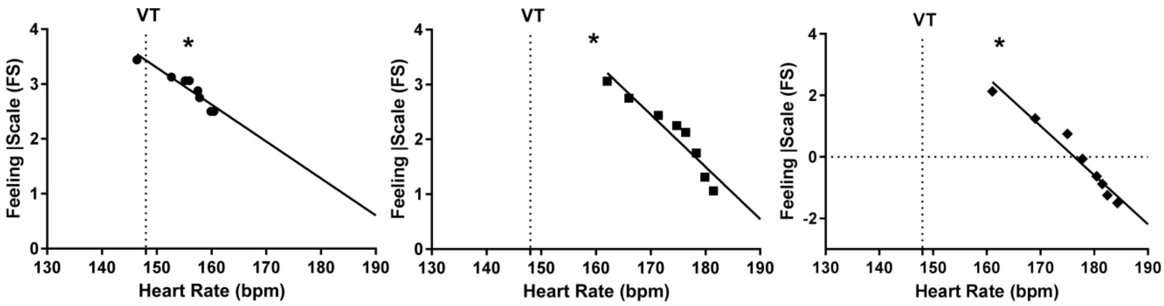

Figure 6.2 Correlation analysis between feeling scale and heart rate during high-intensity interval exercise work intervals performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Abbreviations: Ventilatory threshold (VT), which is denoted by the vertical dotted line. *Significantly negative correlations. See text for details.

FAS responses during the HIIE protocols are illustrated in Figure 6.3. FAS showed a significant condition by interval number interaction (*P*=0.04). FAS was significantly lower during 70%HIIE than 100%HIIE at work interval 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 minutes pre was significant at work interval 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).

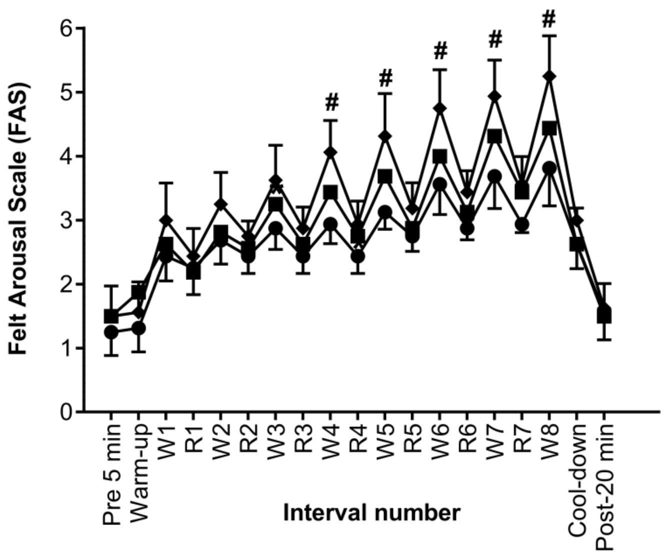

Figure 6.3 Felt arousal scale during the work and recovery phases of high-intensity interval exercise performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Where, W= work interval and R= recovery interval. #Significant difference between 70%HIIE and 100%HIIE. Error bars are presented as standard deviation. See text for details.

Affective responses (valence and activation) during the work and recovery intervals for HIIE protocols were plotted onto a circumplex model (Figure 6.4). 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.

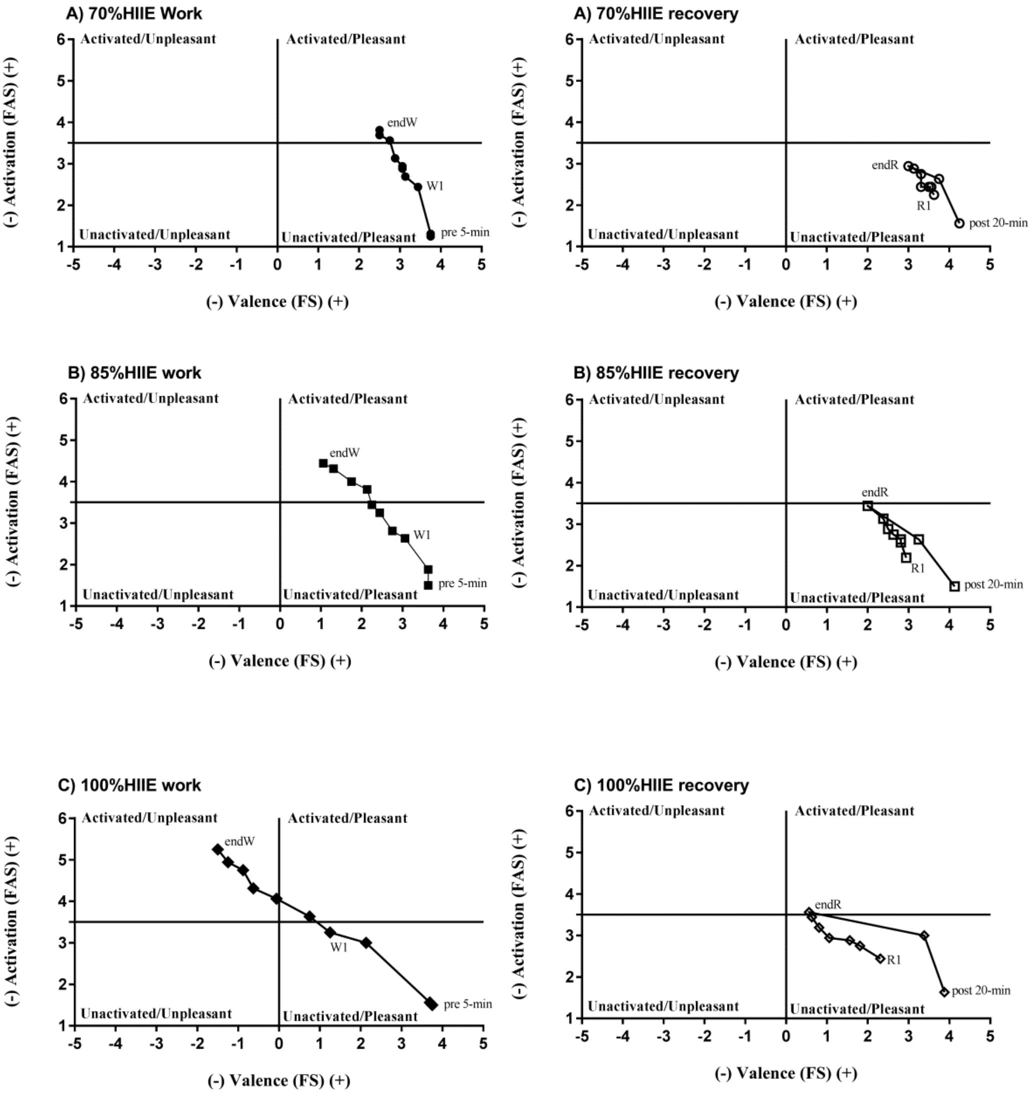

Figure 6.4 Valence (Feeling scale) and activation (Felt arousal scale) during the work and recovery interval of high-intensity interval exercise performed at 70% peak power (70%HIIE) (A), 85% peak power (85%HIIE) (B) and 100% peak power (100%HIIE) (C) plotted onto the circumplex model. 70%HIIE work interval (●), 85%HIIE work 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, and endR= recovery interval 7. See text for details.

6.6.3 Exercise enjoyment responses

The enjoyment responses during the HIIE protocols are illustrated in Figure 6.5. 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 interval 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-interval 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, see Figure 6.6).

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 minutes after); 70%HIIE vs. 100%HIIE, ES=0.15 (immediately) and 0.30 (20 minutes after); 85%HIIE vs. 100%HIIE, ES=0.29 (immediately) and 0.36 (20 minutes after)), but there was a main effect of time (*P*=0.001) for PACES. PACES was significantly higher 20 minutes 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 minutes 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).

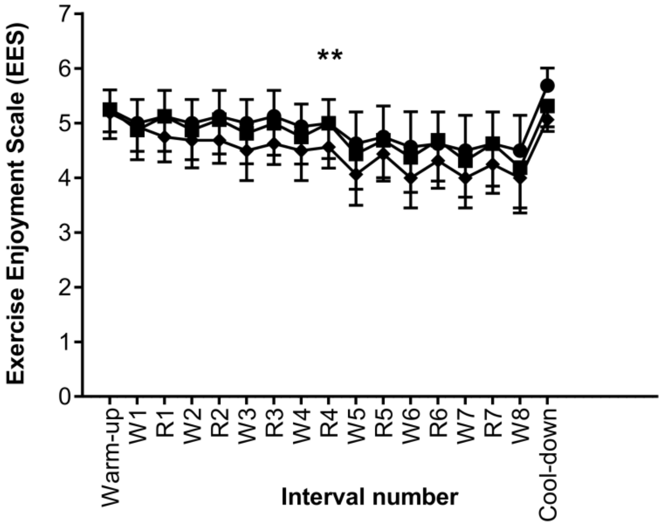

Figure 6.5 Exercise enjoyment scale during the work and recovery phases of high-intensity interval exercise performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Where, W= work interval and R= recovery interval. **Significant main effect for interval number. Error bars are presented as standard deviation. See text for details.

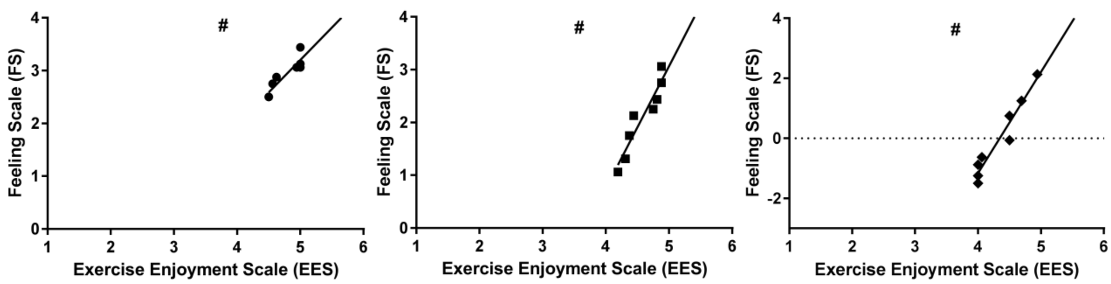

Figure 6.6 Correlation analysis between feeling scale and exercise enjoyment scale during high-intensity interval exercise work intervals performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Abbreviations: Ventilatory threshold (VT), which is denoted by the vertical dotted line. #Significantly positive correlations. See text for details.

6.6.4 Rating of perceived exertion responses

The RPE responses during HIIE are illustrated in Figure 6.7. 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, see Figure 6.8).

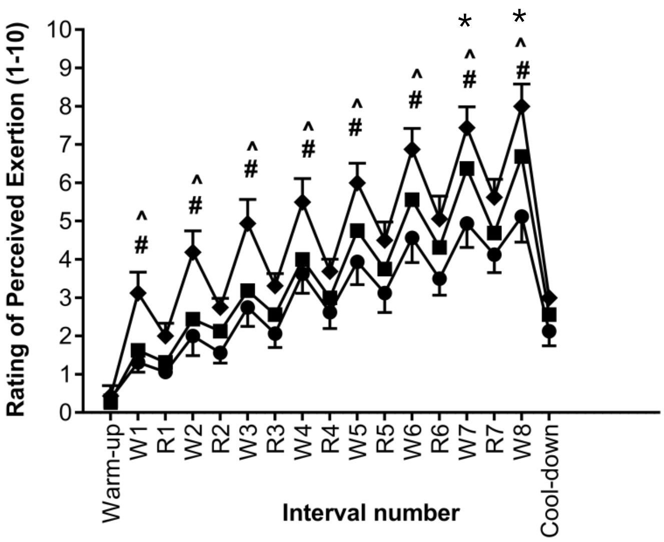

Figure 6.7 Rating of perceived exertion during the work and recovery phases of the high-intensity interval exercise performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Where, W= work interval and R= recovery interval. #Significant difference between 70%HIIE and 100%HIIE. ^Significant difference between 85%HIIE and 100%HIIE. *Significant difference between 70%HIIE and 85%HIIE. Error bars are presented as standard deviation. See text for details.

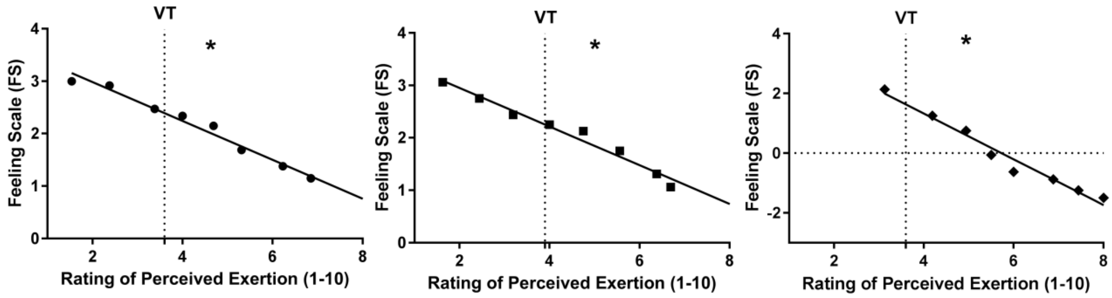

Figure 6.8 Correlation analysis between feeling scale and rating of perceived exertion during high-intensity interval exercise work intervals performed at 70% peak power (70%HIIE; ●), 85% peak power (85%HIIE; ■) and 100%peak power (100%HIIE; ♦). Abbreviations: Ventilatory threshold (VT), which is denoted by the vertical dotted line. *Significantly negative correlations. See text for details.

6.7 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. However, in contrast to the DMT, our findings show that interval exercise performed above the VT does not generate entirely negative affect responses as has been shown during the incremental or continuous mode of exercise in youth (Benjamin et al., 2012, Stych and Parfitt, 2011, Malik et al., 2018b). Furthermore, the majority of the participants reported positive affect responses at the end work interval in 70%HIIE (100%) and 85%HIIE (87%) whereas most of the participants (87%) reported unpleasant feelings only after 100%HIIE. Consistent with recent HIIE work in adolescents (Malik et al., 2018b), we observed a more positive affect during HIIE recovery intervals than the work intervals for all conditions (see Figure 6.1), 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.

Consistent with the study hypotheses and previous HIIE studies (Thackray et al., 2016, Boyd et al., 2013), 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 work interval incorporating 5 or 10 × 1 minute running intervals at 100% MAS separated by 1 minute recovery in adolescent girls. Boyd et al. (2013) found significantly lower affect scores (less pleasurable) during HIIE performed at 100% PPO compared to HIIE performed at 70% PPO 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 (Ekkekakis and Petruzzello, 1999, Bixby et al., 2001). Although 100%HIIE evoked positive affect during the earlier work intervals in the current study, the greater reduction from baseline (i.e. 5 minutes 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., 2018b). As postulated by the DMT, during high-intensity exercise, a deregulation of the 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., 2005b). Malik et al. (2018b) propose that increases in HR across HIIE work intervals may intensify the body's physiological and exertional stress and potentially generate a burning/pain sensations, thus leading to a less positive affect experienced during HIIE. This notion further supported via the positive correlation between affect with HR and RPE across all conditions in this present study. Our findings also revealed similar average HR responses between 85%HIIE and 100%HIIE across the work intervals (see Table 6.2) but 100%HIIE elicited higher perceived exertion than 85%HIIE. Oliveira et al. (2015) reported that RPE was a better predictor of the affective responses during high-intensity exercise than physiological responses (e.g. HR and $\dot{V}O_2$). 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.

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. (2018b) who also found significant increases in activation with further decreases in affect during subsequent HIIE work intervals performed at 90% MAS. 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 6.3). 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% PPO 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 finding extend recent work involving HIIE performed at 90% MAS in adolescent boys (Malik et al., 2018b) 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. Although affect and enjoyment are not identical constructs (i.e. enjoyment arises with significant cognitive elaboration, but not for affect), we observed a strong positive correlation between enjoyment and affect responses during HIIE in all conditions, indicating that affective experience and feelings of enjoyment do overlap during HIIE in adolescents. In regard to the post-enjoyment responses, we found a positive correlation between the PACES scores (i.e. immediately after and 20 minutes 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 Raedeke (2007) who found that enjoyment responses following aerobic exercise were positively related to increases in positive affect but unrelated to changes in negative affect in young adults. Decker and Ekkekakis (2016) also reported that greater post-enjoyment in CMIE 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 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).

However, only HIIE performed at 85% or 100% PPO elicited a maximal cardiorespiratory response based on the cut-off point of ≥90% HR_{max} in the majority (~87%) of adolescents. Previous HIIE studies in youth have reported that ≥90% HR_{max} may serve as the criterion for compliance with the HIIE protocol to improve cardiometabolic and fitness health adaptation in youth (Taylor et al., 2015, Malik et al., 2017). Implications of using HIIE performed at 100% PPO 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. However, previous studies have consistently shown a gradual decline of affect responses during exercise regardless of the intensity (moderate vs. high) and type of exercise (interval vs. continuous) in youth (Stych and Parfitt, 2011, Malik et al., 2018b). 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 & Kahneman, 1993), and both are representative of the overall interpretation of an exercise session (Parfitt & Hughes, 2009; Hargreaves & Stych, 2013) to predict future adherence (Rhodes & Kates 2015). However, it appears that HIIE performed at 85% PPO 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., 2018b). 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. Given that a variety of HIIE protocols have emerged in the paediatric literature, the protocol used in the present study should be considered as only one of a multitude of possibilities. Other HIIE protocols (e.g. different work interval durations and intensities, or different modalities) may generate different perceptual and physiological responses. However, in this study, we have adopted a commonly used HIIE protocol that has been shown to generate multiple health benefits in adolescents (Bond et al., 2017). 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).

6.8 Practical Implications

This study extends the practical use of simple tools of psychometric measurement to prescribe and monitor HIIE as in Chapters 4 and 5 by represents the combining data of HR and psychometric tools (i.e. FS, RPE, and EES scale) with HIIE with different intensities. By using a similar example in Chapters 4 and 5 (i.e. school based intermittent exercise), teachers or educators could instruct the students to maintain at least a ‘good’ feeling (between +2 to +4 on FS) for the initial four repititions by using the FS. This guideline may allow the students to self-select an intensity indicative of higher intensity levels (e.g. 70% to 85% PPO) across the exercise bout while preserving the pleasurable feelings (between +1 to +3 on FS). If the teachers set FS at +2 to 0 (‘fairly good’ to ‘neutral’) during the initial repetitions, the students may choose to run/cycle at a faster pace which leads to a greater physical exertion (e.g. RPE scores between 3-5; ‘getting more tired’ to ‘tired’) and greater HR response (e.g. ~90%-93% HR_{max}). Consequently, students may not be able to maintain the pleasurable feelings across the repetitions and may elicit unpleasant feeling at the later running/cycling repetitions (e.g. below -1 ‘fairly bad’ on FS). However, teachers may instruct the students to maintain a pace that makes them feel ‘fairly good’ during the last four repetitions to achieve sufficient levels of HR_{max} (>90%HR_{max}).

6.9 Conclusions

In conclusion, our data comprehensively extends previous work on adolescents and indicates that some permutations of HIIE (i.e. 70% and 85% PPO) 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 CHIE and incremental exercise to exhaustion. HIIE performed at 100% PPO, 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% PPO for HIIE could potentially serve as suitable alternative HIIE prescription to be adopted for the promotion of health benefits in youth.

CHAPTER 7: Perceptual and prefrontal cortex haemodynamic responses to high-intensity interval exercise with decreasing and increasing work-intensity in adolescents

7.1 Abstract

Purpose: Affect experienced during 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 PFC 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 x 1 minute work intervals at 100% to 70% ($HIIE_{H-L}$), 70% to 100% ($HIIE_{L-H}$) or 85% (85%HIIE) PPO separated by 75 seconds recovery. Affect, enjoyment and cerebral haemodynamics (ΔO_2Hb, ΔHHb) and 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 85%HIIE 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 85%HIIE 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 85%HIIE 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 85%HIIE and $HIIE_{L-H}$ which bring significant greater affect and enjoyment toward the end HIIE work-interval, implicating the feasibility and adoption of this protocol for health promotion in youth. Also, changes in PFC haemodynamics are associated with the affect during HIIE.

7.1 Introduction

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 HR) and exertional stress (e.g. increased 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 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., 2005b). The DMT postulates that the dominant cognitive factor during exercise in the heavy exercise intensity domain (i.e. exercise performed above the 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 RCP). 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., 2005b). 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 PPO, 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 x 1 minute performed at 90% PPO) in youth (Malik et al., 2018b). The HIIE protocol also facilitated higher post-exercise enjoyment and preference compared to CMIE or MIIE (Malik et al., 2017, Malik et al., 2018b). 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 (H-L) or increasing (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% PPO) 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., 2018b), 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 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 ΔO_2Hb in the presence of increased cerebral ΔHHb (Ekkekakis and Acevedo, 2006). Tempest et al. (2014) measured ΔO_2Hb in the PFC during an incremental test to exhaustion using 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 TOI) in adolescents during H-L (100% to 70% of PPO; $HIIE_{H-L}$), L-H (70% to 100% of PPO; $HIIE_{L-H}$) and constant (85% PPO; 85%HIIE) HIIE work intervals. We hypothesised that $HIIE_{H-L}$ would elicit more positive affect (i.e. more pleasurable) and an elevated cerebral oxygenation towards the end of the exercise bout compared to $HIIE_{L-H}$ and 85%HIIE.

7.2 Methods

7.2.1 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., 2018b). 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.

7.2.2 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).

7.2.3 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. 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 maturers participants were defined as the offset score <-1 year, typical matures 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 hours/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 MVPA using a cut-off point of ≥1140 counts per minute, which was previously validated in youth (Phillips et al., 2013).

7.2.4 Cardiorespiratory fitness

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

7.2.5 High-intensity interval exercise protocols

Participants completed three different HIIE protocols consisting: 1) 2 x 1 minute work intervals performed at 100%, 90%, 80% and 70% PPO (total of 8 work intervals), interspersed with 75 s recovery at 20 W ($HIIE_{H-L}$); 2) 2 x 1 minute work intervals performed at 70%, 80%, 90% and 100% PPO (total of 8 work intervals), interspersed with 75 s recovery at 20 W ($HIIE_{L-H}$); and 3) 8 x 1 minute work intervals performed at 85% PPO, interspersed with 75 s recovery at 20 W (85%HIIE). A 3 minutes warm-up and a 2 minutes cool down was provided before and after each HIIE condition. The 85%HIIE protocol was used as the 'control' condition, as this is a common protocol for delivery of HIIE in youth (Bond et al., 2017). The HIIE protocols were matched for exercise duration (i.e. 22 minutes 15 s), duration of the work and recovery intervals, and total (external) work performed.

7.3 Experimental measures

A detailed explanation of the gas exchange, HR, affect, enjoyment and RPE measurements is presented in Chapters 5 and 6.

7.3.1 Cerebral hemodynamics

Cerebral hemodynamics were measured non-invasively using NIRS (NIRO 200 Hamamatsu Photonics, Hamamatsu, Japan). The emitter and detector were encased in a rubber holder with a separation distance of 4 cm. Age-specific differential pathlength factors were calculated using the modified Beer-Lambert equation to provide a measure of the concentration changes (micromolar; mM) in cerebral ΔO_2Hb, cerebral ΔHHb and TOI (Duncan et al., 1996). The probes were placed over the left hemisphere (dorsolateral prefrontal cortex areas; midpoint between Fp1-F3, of the international 10-20 system for EEG electrode placement) in line with previous studies in youth (e.g. Ganesan et al., 2016, Luszczyk et al., 2011). The probes were secured to the skin using a double adhesive sticker. An elastic black bandage was placed over the holders around the forehead. A 30 s baseline measure of cerebral hemodynamics was recorded before all HIIE conditions. Baseline measures were subtracted from the data extracted during exercise. Therefore, ΔO_2Hb and ΔHHb represent the change (from baseline) in the hemodynamic response at selected points during exercise. The TOI represents a measure of tissue oxygen saturation (the ratio of O_2Hb to total Hb); therefore, adjustments for baseline were not required. These variables were time aligned with the gas exchange data obtained during each work and recovery interval and 10-s averages were taken at the end of the work and recovery intervals for further analysis.

7.4 Statistical analyses

All statistical analyses were conducted using SPSS (SPSS 24.0; IBM Corporation, Armonk, NY, USA). The Shapiro-Wilks test was used to test normality of distribution for the dependent variables. Descriptive characteristics (mean ± standard deviation) between boys and girls were analysed using independent samples t-tests. Data were analysed using a mixed model ANOVA to examine differences in affect, enjoyment, PFC hemodynamics, RPE, and cardiorespiratory responses between HIIE protocols over time (e.g. the work and recovery intervals) and experimental orders (prescribed first, second or third). As the inclusion of sex into the ANOVA model did not reveal a significant interaction effect for all outcomes, data were subsequently pooled for analysis. A series of one-way repeated measure ANOVAs were also conducted to examine the magnitude of changes from baseline across the work interval in affect responses within each HIIE protocol. In the event of significant effects ($P<0.05$), follow-up Bonferroni post hoc test were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using ES (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 between affect responses with PFC hemodynamics and post-exercise enjoyment.

7.5 Results

The participants' descriptive characteristics are presented in Table 7.1. Fourteen participants (seven boys) were deemed to have a low level of fitness indicative of increased cardiometabolic risk. One girl was categorised as being overweight. A total of four boys were categorised as a late maturers (<-1 of maturation offset) and two girls were categorised as an early maturers (>+1 of maturation offset). The remaining nine participants were categorised as typical maturers. A total of two boys and one girl were achieving the recommended guideline of 60 minutes of MVPA per day. The remaining 13 participants were not achieving the MVPA guideline. The power output for the HIIE conditions was as follow: 70% PPO = 84 ± 12 W, 80% PPO = 96 ± 14 W, 85% PPO = 102 ± 15 W, 90% PPO = 108 ± 16 W and 100% PPO = 120 ± 17 W. All conditions exhibited the same total work performed (65.4 ± 7.3 kJ). All participants successfully completed the HIIE conditions with no adverse events. The inclusion of experimental orders into the ANOVA model did not reveal a significant interaction effect for all outcomes (all $P>0.33$), showing that the counterbalance order did not influence the perceptual and physiological responses in this present study.

Table 7.1 Descriptive characteristics of the participants (N = 16)

	Boys (n=8)	Girls (n=8)	P- value	ES
Age (y)	12.4 ± 0.7	12.6 ± 0.8	0.49	0.27
Body mass (kg)	47.7 ± 6.9	47.8 ± 5.2	0.99	0.02
Stature (m)	1.56 ± 0.10	1.55 ± 0.09	0.82	0.11
BMI (kg·m^{-2})	18.9 ± 2.2	19.1 ± 4.1	0.89	0.06
Body fat (%)	15.1 ± 3.9	23.0 ± 8.8	**0.04**	1.16
MPA per day (min)	37 ± 12	29 ± 13	0.20	0.64
VPA per day (min)	4 ± 2	3 ± 1	0.64	0.63
MVPA per day (min)	41 ± 16	32 ± 14	0.22	0.60
$\dot{V}O_2$ (L·min^{-1})	1.48 ± 0.21	1.46 ± 0.24	0.91	0.09
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	35.7 ± 3.8	33.2 ± 3.2	0.17	0.69
HR_{max} (bpm)	189 ± 7	186 ± 2	0.27	0.58
HR at VT (bpm)	150 ± 8	153 ± 9	0.17	0.53
VT (L·min^{-1})	0.75 ± 0.13	0.69 ± 0.13	0.38	0.46
VT (%$\dot{V}O_{2\,max}$)	49.8 ± 11.3	47.1 ± 7.4	0.58	0.28

Values are reported as mean ± standard deviation. Abbreviations: BMI, body mass index; MPA, moderate physical activity; VPA, vigorous physical activity; 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.

7.5.1 Cardiorespiratory responses

Cardiorespiratory data from the exercise conditions for boys and girls are presented in Table 7.2. There was a significant condition by interval number interaction for HR (all P<0.01). $HIIE_{L\text{-}H}$ and 85%HIIE elicited higher peak HR to $HIIE_{H\text{-}L}$ (all P<0.05). Also, $HIIE_{H\text{-}L}$ generated a lower HR response (both absolute and relative) compared to 85%HIIE and $HIIE_{L\text{-}H}$ at work interval 8 (162 ± 6 (86 %HR_{max}) vs. 179 ± 4 (95 %

HR_{max}), ES=3.33; 162 ± 6 vs. 183 ± 4 (97 % HR_{max}), ES=3.62, respectively). All participants (n=16, 100% of participants) reached the cut-off point of ≥90% HR_{max} during $HIIE_{L-H}$ and 15 (93%) and 12 (75%) participants reached the cut-off during 85%HIIE and $HIIE_{H-L}$, respectively.

Table 7.2 Cardiorespiratory responses to high-intensity interval exercise with different protocols.

	85%HIIE	$HIIE_{H-L}$	$HIIE_{L-H}$
Average HR (bpm)	155 ± 7	153 ± 5	152 ± 4
Average % HRmax	83 ± 4	82 ± 4	81 ± 3
Peak HR (bpm)	179 ± 4$^{\#}$	172 ± 6$^{\wedge *}$	183 ± 4$^{\#}$
Peak %HRmax	96 ± 4$^{\#}$	92 ± 4$^{\wedge *}$	97 ± 1$^{\#}$
Average $\dot{V}O_2$ (L·min^{-1})	0.92 ± 0.13	0.91 ± 0.14	0.90 ± 0.17
Average $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	63 ± 9	63 ± 10	62 ± 11
Peak $\dot{V}O_2$ (L·min^{-1})	1.23 ± 0.12	1.20 ± 0.15	1.23 ± 0.19
Peak $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	84 ± 11	81 ± 10	84 ± 11

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 gas exchange.

$^{\#}$Significant difference between $HIIE_{H-L}$ (P< 0.05).
$^{\wedge}$Significant difference between $HIIE_{L-H}$ (P< 0.05).
*Significant difference between 85%HIIE (P< 0.05).

7.5.2 Affective responses

FS responses during the HIIE work intervals are illustrated in Figure 7.1. FS showed a significant condition by interval number interaction effect (P<0.01). FS was significantly lower during $HIIE_{H-L}$ than $HIIE_{L-H}$ (all $P<0.001$, ES=1.32 to 1.75) and 85%HIIE (all $P<0.008$, ES=0.96 to 1.17) at work intervals 1 to 3. However, FS was significantly higher during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 and 8 ($P<0.001$, ES=1.46 to 1.67) and 85%HIIE at work interval 8 ($P=0.049$, ES=0.83). FS was also significantly greater during 85%HIIE than $HIIE_{L-H}$ at work intervals 7 and 8 (all $P<0.04$, ES=0.70 to 1.74). ΔFS was significantly lower in $HIIE_{H-L}$ than 85%HIIE ($P<0.01$, 0.4 ± 0.9 vs. 2.0 ± 1.5, ES=1.29) and $HIIE_{L-H}$ ($P<0.01$, 0.4 ± 0.9 vs. 3.2 ± 1.3, ES= 2.50). ΔFS was also significantly lower in 85%HIIE than $HIIE_{L-H}$ ($P=0.03$, 2.0 ± 1.5 vs. 3.2 ± 1.3, ES= 0.85). The decline in FS from baseline (5 minutes pre) was significant from work intervals 3 to 8 (all $P<0.03$; ES=0.92 to 2.07) and from work interval 5 to 8 (all $P<0.005$; ES=1.66 to 3.09) in 85%HIIE and $HIIE_{L-H}$, respectively. In contrast, the decline in FS was only significant from baseline up to work-interval 6 during $HIIE_{H-L}$ (all $P<0.014$; ES=1.29 to 1.47). FS remained positive at work interval 8 during $HIIE_{H-L}$ (2.2 ± 1.3 on FS score) in all participants (n =16, 100%), in 15 participants (93%) during 85%HIIE (1.1 ± 1.3 on FS score) and in 12 participants (75%) during $HIIE_{L-H}$ (0.3 ± 1.0 on FS score).

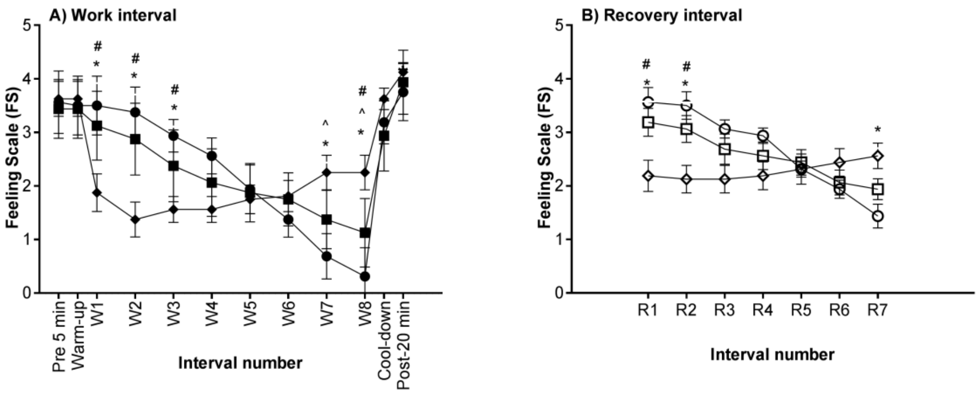

Figure 7.1 Feeling scale during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($\text{HIIE}_{\text{H-L}}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($\text{HIIE}_{\text{L-H}}$;●), high-to-low recovery interval ($\text{HIIE}_{\text{H-L}}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($\text{HIIE}_{\text{L-H}}$; ○). Where, W= work interval and R= recovery interval. [#]Significant difference between $\text{HIIE}_{\text{H-L}}$ with 85%HIIE (*P*<0.01). [^]Significant difference between 85%HIIE with $\text{HIIE}_{\text{L-H}}$ (*P*<0.01). *Significant difference between $\text{HIIE}_{\text{H-L}}$ with $\text{HIIE}_{\text{L-H}}$ (*P*<0.01). Error bars are presented as standard deviation. See text for details.

FAS responses during the HIIE work intervals are illustrated in Figure 7.2. FAS showed a significant condition by interval number interaction (*P*<0.01). FAS was significantly greater during $\text{HIIE}_{\text{H-L}}$ than $\text{HIIE}_{\text{L-H}}$ at work-intervals 1 to 4 (all *P*<0.001; ES = 0.91 to 1.78), but significantly lower during $\text{HIIE}_{\text{H-L}}$ than $\text{HIIE}_{\text{L-H}}$ at work-intervals 7 and 8 (all *P*<0.01; ES = 2.08 to 1.59). FAS was also significantly higher during $\text{HIIE}_{\text{H-L}}$ than 85%HIIE at work-intervals 1 and 2 (all *P*<0.006; ES= 1.29 to 1.45), but significantly lower during $\text{HIIE}_{\text{H-L}}$ than 85%HIIE at work-interval 8 (*P*= 0.002; ES = 1.46).

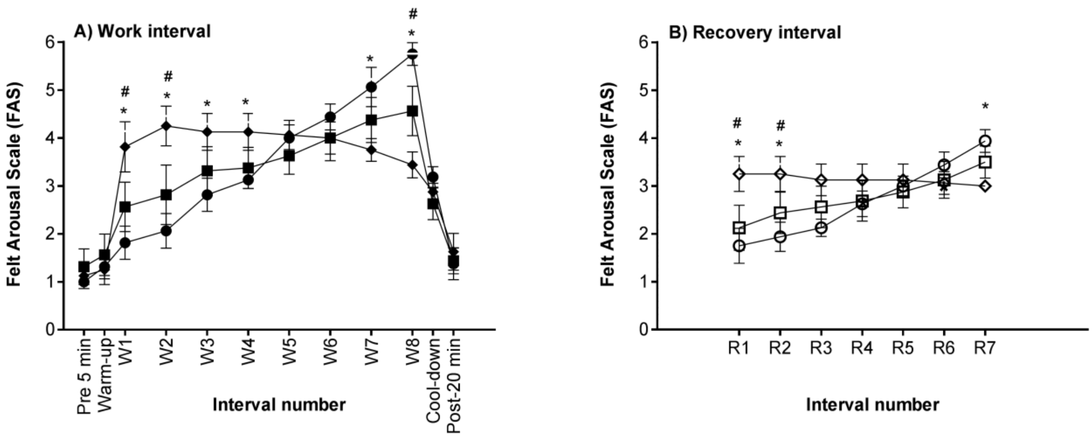

Figure 7.2 Felt arousal scale during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H-L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L-H}$;●), high-to-low recovery interval ($HIIE_{H-L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L-H}$; ○). Where, W= work interval and R= recovery interval. #Significant difference between $HIIE_{H-L}$ with 85%HIIE (P<0.01). *Significant difference between $HIIE_{H-L}$ with $HIIE_{L-H}$ (P<0.01). Error bars are presented as standard deviation. See text for details.

Affective responses (valence and activation) during the work and recovery intervals for the HIIE protocols were plotted onto a circumplex model (Figures 7.3). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant during the work intervals for all conditions, but during $HIIE_{H-L}$ affective responses shifted back to the unactivated/pleasant quadrant at work interval 8. The affective responses remained in the unactivated/pleasant quadrant for HIIE recovery intervals in all conditions.

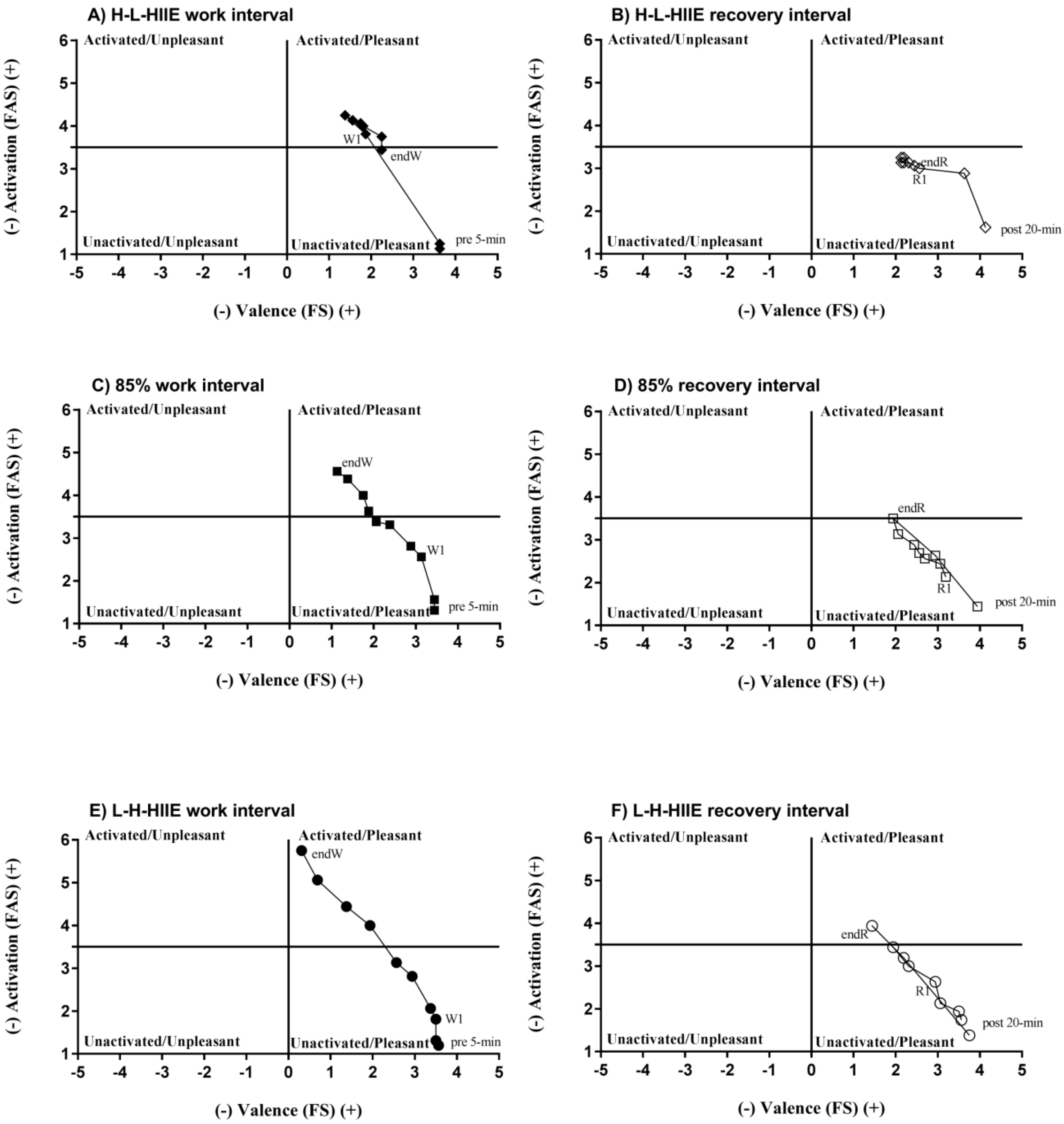

Figure 7.3 Valence (Feeling scale) and activation (Felt arousal scale) during the work and recovery interval of high-intensity interval exercise performed at high-to-low peak power (A and B), 85% peak power (C and D) and low-to-high peak power (E and F) plotted onto the circumplex model. Where, W= work interval, R= recovery interval, endW= work interval 8, and endR= recovery interval 7. See text for details.

7.5.3 Exercise enjoyment responses

Enjoyment responses during the HIIE work intervals are illustrated in Figure 7.4. EES showed a significant condition by interval number interaction (P<0.01). EES was significantly lower during $HIIE_{H\text{-}L}$ than 85%HIIE and $HIIE_{L\text{-}H}$ at work intervals 1 and 2 (all P<0.043; ES>0.89), but significantly greater than $HIIE_{L\text{-}H}$ at work-interval 8 (P=0.01; ES=1.82). EES was also significantly greater during 85%HIIE than $HIIE_{L\text{-}H}$ at work-interval 8 (P=0.017; ES= 1.26).

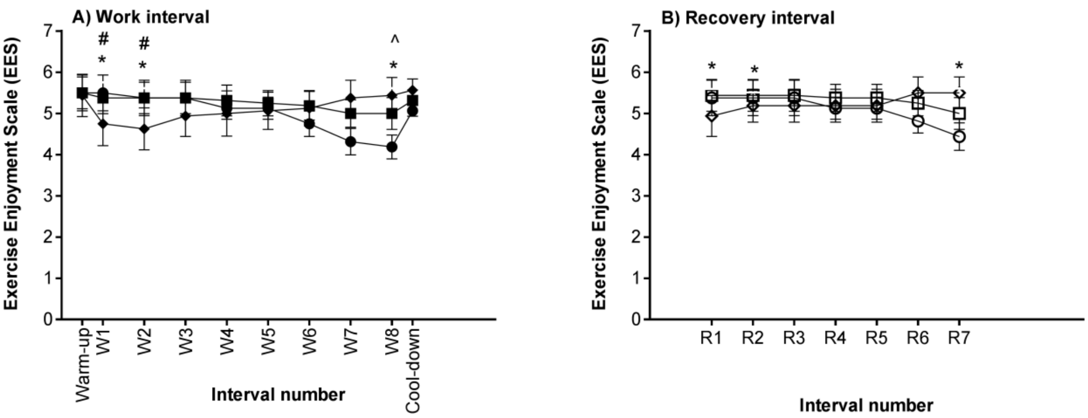

Figure 7.4 Exercise enjoyment scale during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H\text{-}L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L\text{-}H}$;●); high-to-low recovery interval ($HIIE_{H\text{-}L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L\text{-}H}$; ○). Where, W= work interval and R= recovery interval. #Significant difference between $HIIE_{H\text{-}L}$ with 85%HIIE (P<0.01). ^Significant difference between 85%HIIE with $HIIE_{L\text{-}H}$ (P<0.01). *Significant difference between $HIIE_{H\text{-}L}$ with $HIIE_{L\text{-}H}$ (P<0.01). Error bars are presented as standard deviation. See text for details.

There was no condition by time interaction (P=0.58) or effect of condition (P=0.62), but there was a main effect of time (P<0.001) for PACES. PACES was significantly higher 20-min post compared to immediately after HIIE ($HIIE_{H\text{-}L}$, 76 ± 2 vs. 74 ± 3, *P*=0.02, ES=0.67; 85%HIIE, 76 ± 3 vs. 73 ± 2, *P*=0.002, ES=1.18; $HIIE_{L-H}$, 75 ± 3 vs. 73 ± 3, *P*=0.049, ES=0.67, respectively). There was a positive correlation between the FS at work-interval 8 and PACES score immediately after and 20 minutes post $HIIE_{H-L}$ (*P*=0.031, *r*=0.55; *P*=0.041, *r*=0.58, respectively) and 85%HIIE (*P*=0.036, *r*=0.65; *P*=0.046, *r*=0.63, respectively), but not in $HIIE_{L-H}$ (*P*=0.18, *r*=0.36; *P*=0.29, *r*=0.28, respectively). There were no significant correlations between ΔFS and PACES immediately after and 20 minutes post across all HIIE conditions (all *P*>0.12; all *r*<0.32).

7.5.4 Rating of perceived exertion responses

The RPE responses during HIIE are illustrated in Figure 7.5. RPE showed a significant condition by interval number interaction (*P*<0.01). RPE was significantly greater during $HIIE_{H-L}$ than 85%HIIE and $HIIE_{L-H}$ at work-intervals 1 to 3 (all *P*<0.016; all ES at work interval 1 > 3.06; ES at work interval 3 > 1.26), but significantly lower than 85%HIIE and $HIIE_{L-H}$ at work-intervals 7 to 8 (all *P*<0.014; all ES > 1.14).

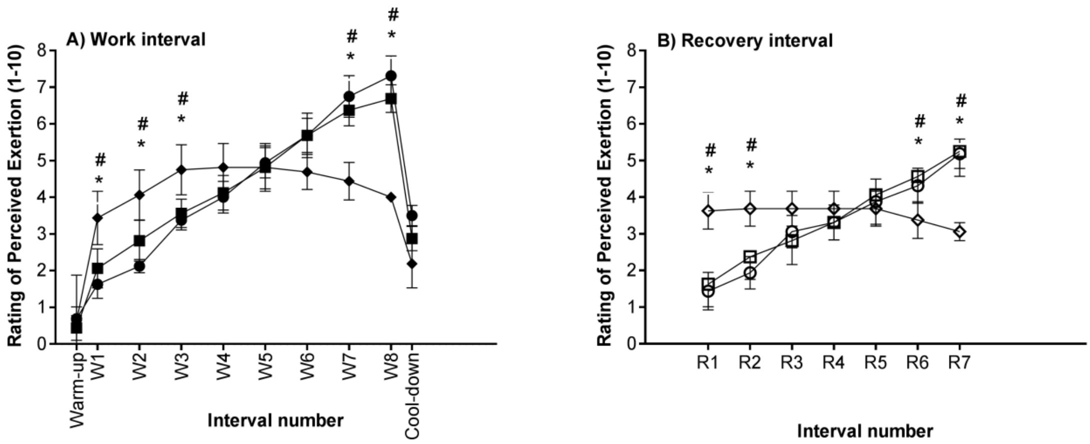

Figure 7.5 Rating of perceived exertion during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H-L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L-H}$;●); high-to-low recovery interval ($HIIE_{H-L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L-H}$; ○). Where, W= work interval and R= recovery interval. [#]Significant difference between $HIIE_{H-L}$ with 85%HIIE (*P*<0.01). *Significant difference between $HIIE_{H-L}$ with $HIIE_{L-H}$ (*P*<0.01). Error bars are presented as standard deviation. See text for details.

7.5.5 Cerebral haemodynamics

The cerebral haemodynamics (ΔO_2Hb, ΔHHb and TOI) during the HIIE protocols are illustrated in Figure 7.6, 7.7 and 7.8. There was no condition by interval number interaction (*P*=0.78) or effect of condition (*P*=0.87), but there was a main effect of interval number (*P*<0.01) for cerebral ΔO_2Hb. Cerebral ΔO_2Hb increased from warm-up at work intervals 5 to 8 for all conditions (all *P*<0.042, all ES>0.39). There was a positive correlation between ΔO_2Hb and FS in $HIIE_{H-L}$ (*P*=0.034, *r*= 0.53), but negative correlation between ΔO_2Hb and FS in 85%HIIE and $HIIE_{L-H}$ across the work intervals (all *P*<0.043; *r*= -0.62; *r*= -0.65, respectively). There was a significant positive correlation between the FS and ΔO_2Hb at work-interval 8 in all conditions (all *P*<0.034; all *r*>0.67).

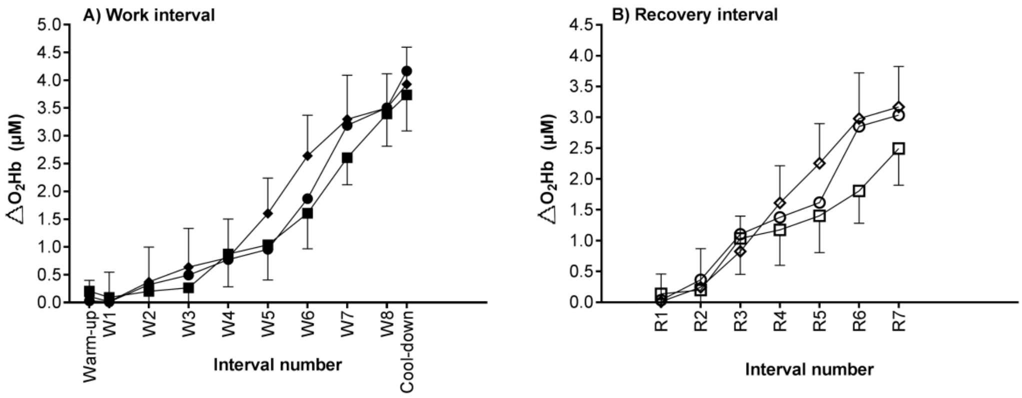

Figure 7.6 Cerebral oxygenation during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H-L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L-H}$;●); high-to-low recovery interval ($HIIE_{H-L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L-H}$; ○). Where, W= work interval and R= recovery interval. Where, W= work interval, R= recovery interval. Error bars are presented as standard deviation. See text for details.

Cerebral ΔHHb showed a significant condition by interval number interaction (P<0.01). Cerebral ΔHHb was significantly lower during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 and 8 (all P<0.035; ES=0.68 to 0.84) and 85%HIIE at work interval 8 (P=0.039; ES=0.40). Cerebral ΔHHb increased from warm-up to work interval 8 during $HIIE_{H-L}$ (all P<0.04; ES=0.86 to 0.62), 85%HIIE (P<0.03; ES=0.84 to 1.48) and $HIIE_{L-H}$ (all P<0.002; ES= 0.48 to 2.07). However, during $HIIE_{H-L}$, no significant differences between work interval 1 and work intervals 7 to 8 were evident for cerebral ΔHHb (all P>0.58, all ES>0.22). There was a negative correlation between ΔHHb and FS responses across the work intervals in all conditions (all P<0.002; $HIIE_{H-L}$, r= -0.73; 85%HIIE, r= -0.84; $HIIE_{L-H}$, r= -0.81). There was a significant negative correlation between the FS and ΔHHb at work-interval 8 in all conditions (all P<0.014; all r>-0.60).

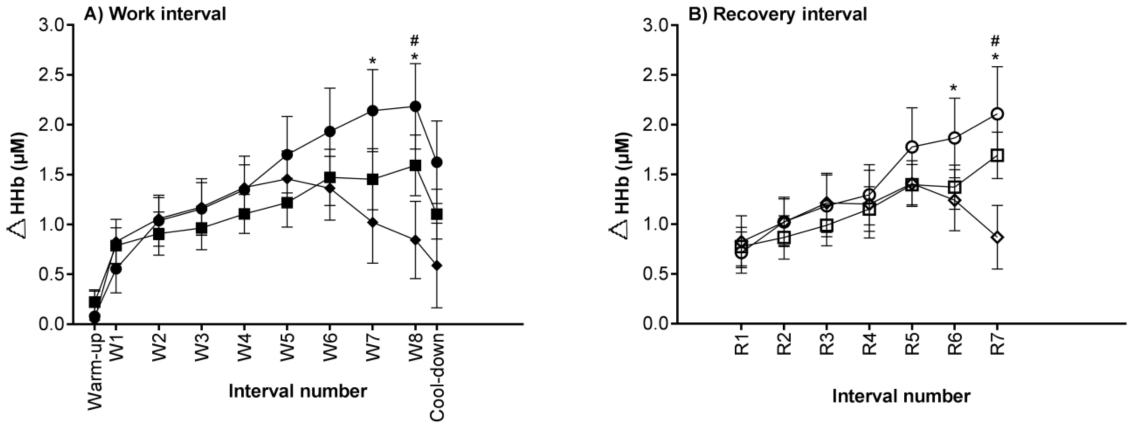

Figure 7.7 Cerebral deoxygenation during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H-L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L-H}$;●); high-to-low recovery interval ($HIIE_{H-L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L-H}$; ○). Where, W= work interval and R= recovery interval. Where, W= work interval, R= recovery interval. #Significant difference between $HIIE_{H-L}$ with 85%HIIE (P<0.05). *Significant difference between $HIIE_{H-L}$ with $HIIE_{L-H}$ (P<0.05). Error bars are presented as standard deviation. See text for details.

TOI showed a significant condition by interval number interaction (P=0.013). TOI was significantly greater during $HIIE_{H-L}$ than $HIIE_{L-H}$ at work intervals 7 to 8 (all P<0.011; ES= 0.79 to 0.98) and 85%HIIE at work interval 8 (P=0.044; ES=0.38). TOI declined from warm-up at work intervals 5 to 8 during $HIIE_{L-H}$ (all P<0.02; ES=0.59 to 0.90) but increased from warm-up at work interval 8 (P=0.039; ES= 0.56) during $HIIE_{H-L}$. There was a positive correlation between TOI and FS responses across the work intervals in all condition (all P<0.001; $HIIE_{H-L}$, r= 0.92; 85%HIIE, r= 0.98; $HIIE_{L-H}$, r= 0.98). There was a significant positive correlation between the FS and TOI at work-interval 8 in all conditions (all P<0.024; all r>0.70).

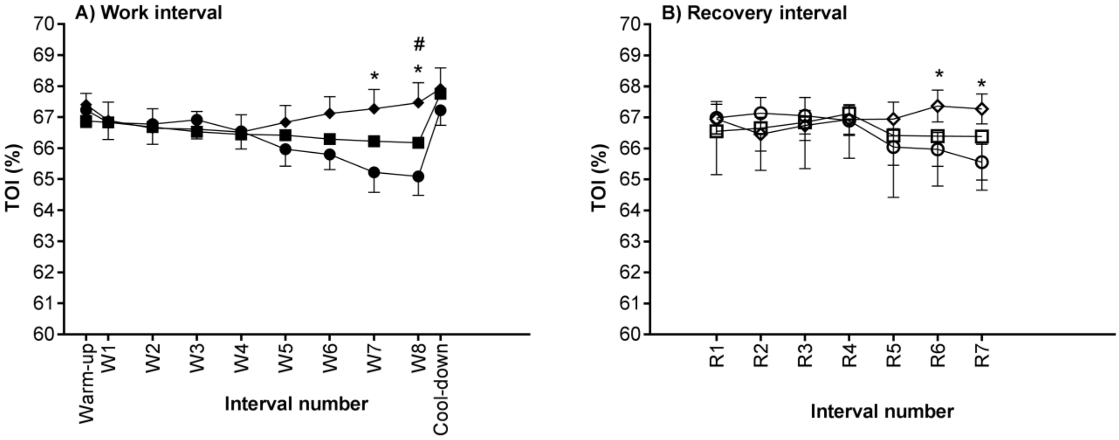

Figure 7.8 Tissue oxygenation index during the work (A) and recovery (B) phases of high-intensity interval exercise with high-to-low work interval ($HIIE_{H-L}$; ♦), 85% work interval (85%HIIE; ■), low-to-high work interval ($HIIE_{L-H}$;●); high-to-low recovery interval ($HIIE_{H-L}$; ◊), 85% recovery interval (85%HIIE; □), and low-to-high recovery interval ($HIIE_{L-H}$; ○). Where, W= work interval and R= recovery interval. Where, W= work interval, R= recovery interval. #Significant difference between $HIIE_{H-L}$ with 85%HIIE (P<0.05). *Significant difference between $HIIE_{H-L}$ with $HIIE_{L-H}$ (P<0.05). Error bars are presented as standard deviation. See text for details.

7.6 Discussion

This study presents novel data on affect, enjoyment and PFC haemodynamic responses during HIIE that consisted of increasing, decreasing, and constant delivery of the workload in adolescent boys and girls. The key findings from this study are: 1) $HIIE_{H-L}$ elicited lower positive affect and enjoyment during the initial work-intervals, but elicited greater positive affect and enjoyment during the later work intervals, compared to $HIIE_{L-H}$ and 85%HIIE; 2) similar enjoyment was observed for all HIIE conditions immediately after and 20 minutes after exercise; 3) similar cerebral ΔO_2Hb was observed across conditions, but $HIIE_{H-L}$ elicited greater TOI in the presence of lower ΔHHb towards the end of the work intervals compared to $HIIE_{L-H}$ and 85%HIIE; 4) affect was strongly correlated with ΔHHb (negatively) and TOI (positively) during work intervals across all HIIE conditions.

In this study, we found a similar pattern of affect responses in the 85%HIIE protocol to Malik et al. (2018b), who observed a decline in affect from baseline during the later stages of HIIE work intervals at 90% of MAS in adolescents boys. In contrast, affect responses only declined for the initial 75% of the total work performed during $HIIE_{H-L}$ (from baseline to work-interval 6) in the current study, resulting in more pleasurable feelings towards the end of work interval than $HIIE_{L-H}$ and 85%HIIE. Indeed, $HIIE_{H-L}$ fostered pleasurable feelings in all participants (100%) compared to 93% and 75% of participants in 85%HIIE and $HIIE_{L-H}$, respectively, during the later HIIE work intervals. A similar pattern was observed by Zenko et al. (2016), who reported improved affect responses towards the end of continuous H-L (120–0% of the power output corresponding to the VT) compared to continuous L-H (0–120%) intensity exercise in healthy adults. It is important to note that all the prescribed HIIE conditions in our study were matched for total exercise duration (i.e. work and recovery) and external work, indicating that the observed changes in affect responses are due to the delivery pattern (e.g. increasing vs. decreasing) of the HIIE work intensity.

We observed greater PFC oxygenation (i.e. reflected by greater TOI in the presence of lower cerebral ΔHHb) during $HIIE_{H-L}$ compared to $HIIE_{L-H}$ and 85%HIIE at the later stages of the work intervals, where the power output was 15% and 30% lower than 85%HIIE and $HIIE_{L-H}$, respectively. The DMT predicts that the reduced positive affect during high-intensity exercise is caused by decreased activity in the PFC and a corresponding increased activity in the subcortical area driven by intensified interoceptive cues (Ekkekakis & Acevedo, 2006). A decrease in PFC activity is associated with reduced oxygen availability due to decreases in cerebral blood flow, meaning a greater increase in fractional oxygen utilisation is needed to meet metabolic demand. This observation typically occurs at exercise intensity above the RCP (Bhambhani et al., 2007, Rooks et al., 2010) and can be indicated by a lower ΔO_2Hb and higher ΔHHb measured using NIRS (Ekkekakis and Acevedo, 2006). Our data showed a significant difference in FS accompanied by a significant difference in TOI and ΔHHb but not in ΔO_2Hb across all HIIE conditions. These observations may suggest the potential link between FS with TOI and ΔHHb compared to ΔO_2Hb. Furthermore, the correlations between FS with TOI and ΔHHb showed a consistent pattern (positive and negative, respectively) across the HIIE conditions, whereas the correlations between FS and ΔO_2Hb exhibited an inconsistent pattern (positive correlation for ΔO_2Hb but negative correlation in both TOI and ΔHHb) across the conditions. We speculate, therefore, that increases in PFC oxygenation (greater TOI in the presence of lower cerebral ΔHHb) during the later stages of the $HIIE_{H-L}$ work intervals reflected better maintenance of the PFC activity levels compared to $HIIE_{L-H}$ and 85%HIIE, resulting in more pleasurable feelings. This potential mechanistic link is further supported via the significant correlation between affect with ΔO_2Hb (positive), TOI (positive) and ΔHHb (negative), respectively, at the end of work intervals in all HIIE conditions. Therefore, our findings show that the ability to increase PFC oxygenation to facilitate more pleasurable feelings at the end of HIIE work interval may be favourable via decreasing work intensity rather than maintaining or increasing the work intensity above the 85% PPO in youth.

We observed lower enjoyment during the earlier work intervals of $HIIE_{H\text{-}L}$ compared to $HIIE_{L\text{-}H}$ and 85%HIIE, but greater enjoyment during the later stages of $HIIE_{H\text{-}L}$ compared to $HIIE_{L\text{-}H}$. These differences in enjoyment responses between HIIE protocols may be related to the strong positive correlation between enjoyment and affective responses. In contrast, a previous study revealed similar levels of enjoyment across work intervals regardless of the intensity used (moderate vs. high) (Malik et al., 2018b). Therefore, our findings extend previous HIIE work by supporting the proposition that H-L and L-H HIIE work intervals could influence enjoyment levels during HIIE.

Similar post-enjoyment (i.e. immediately and 20 minutes after exercise) was observed across all HIIE conditions, but only post-enjoyment in $HIIE_{H\text{-}L}$ and 85%HIIE was positively correlated with affect at the end of HIIE. According to Fredrickson and Kahneman (1993), people tend to recall the peak and end affective responses and are therefore more likely to adhere to the behaviour if the ending is more pleasurable (Parfitt and Hughes, 2009). Moreover, Zenko and colleagues (2016) revealed that recovering of affect responses to more pleasant feelings near the end of exercise bout in H-L facilitates greater positive affective memories compared to L-H even after seven days of exercise. This shows that improvements in pleasurable feelings over time, during exercise, strongly influence retrospective evaluations of the exercise experience (Ariely and Zauberman, 2003, Zauberman et al., 2006). Given that greater positive affect and enjoyment were found during work interval 8 in $HIIE_{H\text{-}L}$ compared to $HIIE_{L\text{-}H}$ and 85%HIIE in this study, it seems plausible to suggest that the $HIIE_{H\text{-}L}$ protocol may be superior to the 85%HIIE and $HIIE_{L\text{-}H}$ protocols in term of facilitating the adoption and maintenance of HIIE in adolescents when it comes to future exercise behaviour.

All the prescribed HIIE protocols elicited sufficient increases in HR (≥90% HR_{max}) in the majority of our participants. It is therefore feasible that performing any of these protocols chronically, as opposed to acutely, could lead to physiological health benefits similar to those observed in other HIIE training studies in youth (Bond et al., 2017). Affect and enjoyment need to be considered, however, when designing an HIIE intervention to promote better implementation, maintenance and adoption of the exercise behaviour. As such, our findings suggest that the $HIIE_{H-L}$ and 85%HIIE (which elicited pleasurable feelings in 100% and 93% of participants, respectively) prescribed in this study could provide an appropriate HIIE strategy for adolescents, but $HIIE_{H-L}$ could offer advancement to the 85%HIIE protocol due to the improvement in pleasurable feelings and enjoyment responses. Although the $HIIE_{L-H}$ protocol generated positive affect responses in 75% of participants, this protocol elicited greater RPE than the other protocols, and the affect experienced was close to the boundary of the activated unpleasant feelings on the circumplex model (see Figure 7.3) due to high arousal (measured by FAS score). This indicates that $HIIE_{L-H}$ could develop feelings of distress and tension, which may potentially lead to exercise avoidant behaviours.

The strengths of this study are noteworthy. The partcipants in this study were insufficiently active and had low cardiorespiratory fitness which could augment the generalisability of our data for PA interventions that are substantially required in youth. Whilst many studies have prescribed HIIE based on the single and constant work intensity (Bond et al., 2017), the current study is the first to prescribe a HIIE protocol relative to decreasing (H-L) and incresing (L-H) delivery of the work intensity and its effect on perceptual (i.e. affect and enjoyment) and physiological responses (i.e. cerebral hemodynamics and HR). Our study also used a non-invasive NIRS technique to provide mechanistic insight into PFC activity in relation to affective responses during HIIE. To establish a more complete picture of the association between PFC haemodynamics and affective responses during HIIE, however, future studies may consider recording multiple areas of the PFC (e.g. the left and right lobe) as differential activation patterns associated with affective responses may occur within multiple areas of the PFC (Tempest et al., 2014). The present study is limited to exercise conducted in a laboratory, which is unlikely to reflect a participant's real-world affective response to exercise. It was necessary to conduct the research in a laboratory setting, however, as a lack of auditory, visual, and social interaction was required to ensure accurate comparison of perceptual (i.e. affect and enjoyment) cardiorespiratory factors (i.e. HR and $\dot{V}O_2$) across the HIIE conditions.

7.7 Practical implications

This study furthers the application and implementation of the HIIE protocol compared to Chapters 4 to 6 by manipulating the direction of work intervals from H-L and L-H. This protocol can be applied in a school setting by using a similar example to that highlighted in Chapters 4 to 6 (intermittent running/cycling exercise). However, to achieve an improvement in pleasurable feelings near the end of the exercise bout, teachers could instruct their students to find a pace that makes them feel "fairly good" (0 to +1) during the initial high-intensity running/cycling phase (initial four repititions) but change the pace that makes them feel 'good' (+3 to +4) for the subsequent four repetitions. This guideline may lead the students to select an intensity that is relatively higher during the initial four work intervals but ending with slightly lower intensity during the last four repetitions. This process can be aided by monitoring an RPE that elicits 'getting more tired' to 'tired' (3-6) which is associated with HR responses corresponding to 90% to 93% HR_{max} during the initial four work intervals. An RPE that elicits ‘getting more tired’ to a ’little tired’ (4-3) on RPE scale associated with HR responses corresponding to 85%-90% HR_{max} can be used as an indicator of the lower work intensity during the final four work intervals. These guidelines can be applied with other forms of HIIE such as circuit exercise, skipping, shuttle runs and game based exercises.

7.8 Conclusion

This study comprehensively extends previous work on the delivery pattern of HIIE work intervals (e.g. H-L and L-H) in adolescents and indicates that HIIE protocols with decreasing work intensity (i.e. H-L) could facilitate greater affective and enjoyment responses in youth. These observations indicate that HIIE may not entirely generate feelings of displeasure (Malik et al., 2018b), and that the prescription and implementation depend on the type of protocol (e.g. decreasing, increasing, or constant) and work intensity used. Our data indicate that the decreasing pattern of $HIIE_{H-L}$ offers advancement to other HIIE protocols (i.e. 85%HIIE and $HIIE_{L-H}$), by increasing positive affect and enjoyment responses towards the end of exercise. This observation supports the $HIIE_{H-L}$ protocol for fostering the adoption and maintenance of HIIE while facilitating health adaptations in youth. Finally, our study provides initial insight into role of PFC haemodynamics and affective responses in youth, showing that an increase in PFC oxygenation may facilitate the increases in positive affect experienced during HIIE.

CHAPTER 8: Influence of personality and self-efficacy on perceptual responses during high-intensity interval exercise in adolescents

8.1 Abstract

Purpose: Inter-individual cognitive factors have been shown to be related to the changes in affect evaluations during CHIE in adolescents, but the role of cognitive factors on affect during HIIE is currently unknown. This study evaluated the influence of personality traits (BAS and BIS) and self-efficacy on affect, enjoyment and perceived exertion during HIIE in adolescents. **Methods**: Participants (N=30; 15 boys; mean age= 12.2 ± 0.4 years) were median split into low vs. high BAS/BIS and self-efficacy groups. All participants performed HIIE consisting of 8 x 1 minute work-intervals at 85% of PPO separated by 75 s recovery (85%HIIE). Affect, enjoyment, and RPE were recorded before, during, and after HIIE. **Results**: The high BAS/low BIS group elicited greater affect and enjoyment compared to low BAS/high BIS group during work-intervals 5 to 8 (all P<0.039, all ES>0.59) and after 85%HIIE for post-enjoyment (all P<0.038, all ES>0.95). Affect and enjoyment were greater in high compared to low self-efficacy group during work-intervals 5 to 8 (all P<0.048, all ES>0.62) but similar post-enjoyment were found (P=0.062). The BAS/BIS groups elicited similar RPE (all P>0.10), but RPE was lower in high than low self-efficacy group at work-intervals 5 to 8 (all P<0.037, ES>0.98). **Conclusions**: Individual differences in personality and self-efficacy influence affect and enjoyment during 85%HIIE. However, 85%HIIE elicited pleasurable feelings regardless of inter-individual cognitive factors, highlighting the feasibility of 85%HIIE as an alternative form of exercise in adolescents.

8.2 Introduction

HIIE has been shown to be a viable exercise protocol for enhancing cardiorespiratory fitness and cardiometabolic health in adolescents (Bond et al., 2017, Costigan et al., 2015). A recent study has shown that a commonly used HIIE protocol (i.e. 8 x 1 minute work interval separated by 75 s recovery) in youth elicited positive affect responses in 84% of participants (Malik et al., 2018b), suggesting that the recovery interval incorporated into HIIE may be preserving the pleasurable feelings. This finding contrasts with the expected pattern of negative affect responses (unpleasant feelings) during high-intensity exercise in youth (i.e. exercise performed above the VT), as predicted by the DMT, which is based on CHIE and an incremental test to exhaustion (Benjamin et al., 2012, Stych and Parfitt, 2011). Therefore, the adoption and implementation of HIIE protocol as a health strategy is promising in youth.

Despite the aforementioned HIIE protocol generating pleasurable feelings in youth, Malik and colleagues (2018b) observed a negative correlation between elevated HR and affect responses across the HIIE work intervals. This observation suggests that the decline in affect (i.e. less pleasurable feelings) during HIIE is related to the influence of physiological factors. According to the DMT (Ekkekakis et al., 2005b), the predominance of interoceptive/physiological cues (e.g. increased HR) or cognitive/psychological cues (e.g. self-efficacy) during high-intensity exercise is related to unpleasant and pleasant feelings, respectively. Previous research has evaluated the relationship between affect responses and physiological responses during HIIE in youth (Malik et al., 2018b), but data on cognitive factors during HIIE have yet to be explored. Indeed, the interaction of an individual's cognitive and physiological factors could influence perceptions that either maintain or enhance the positive affective response during exercise at a given intensity (Rose and Parfitt, 2007).

The DMT postulates that cognitive factors are unique to the individual and are likely to be influenced by self-efficacy, personality traits and goal achievement (Ekkekakis, 2003). Research has investigated personality traits and self-efficacy as the cognitive factors that underlie affective responses to exercise (McAuley and Courneya, 1992, Schneider and Graham, 2009). Regarding personality traits, previous evidence has indicated that extraversion (i.e. tendency to be sociable and seek excitement) as the most consistent dimension of personality characteristics that associated with PA (Rhodes and Smith 2005). Indeed, Gray (1991) has argued that extraversion reflects a combination of high BAS and low BIS activity which represent two main brain systems that are hypothesized to regulate approach and withdrawal behaviour in response to environmental stimuli, respectively. Carver and White (1994) proposed that BAS (approach motivation) individuals are sensitive to the stimuli that are typically associated with a sense of reward and positive feelings (e.g. pleasurable and happiness), whereas BIS (avoidance motivation) individuals are sensitive to the stimuli that are typically associated with a sense of punishment and negative feelings (e.g. frustration and sadness). A previous study in adolescents (aged 14.8 ± 0.46 years) revealed that the BAS group experienced greater enjoyment and pleasurable feelings compared to the BIS group during CMIE and CHIE (Schneider and Graham, 2009). This finding indicates the role of an individual’s personality on affect responses, but this observation was made during continuous exercise where high-intensity exercise was perceived as unpleasant.

With regard to self-efficacy (i.e. confidence to perform the exercise task), a review of research in adolescent has indicated that self-efficacy as a prominent personal determinant to engage with PA behaviour (Van der Horst et al., 2007). Bandura (1986) argued that there is a link between affective responses and the subsequent formation of individual self-efficacy, i.e. pleasurable feelings may reflect high confidence level and unpleasant feelings may reflect low confidence level. Previous studies in adults have consistently reported that individuals with high self-efficacy exhibit more positive affect and a lower RPE compared to low self-efficacy individuals (Tate et al., 1995, Focht, 2013, McAuley and Courneya, 1992). These authors revealed that the differences between low vs. high self-efficacy individuals were increasingly evident at more demanding work intensities (e.g. above 70% of predicted HR_{max}). However, these observations were limited to incremental exercise to exhaustion and continuous exercise in adults, which is untypical of youth patterns of activity and exercise (Barkley et al., 2009).

Given the above, the extent to which affect responses differ according to personality and self-efficacy factors during HIIE has not yet been examined in youth. Elucidating this information may provide insight into how HIIE can elicit a more positive affective response for individuals with unique cognitive factors. Therefore, the purpose of the present study was to evaluate the influence of personality (BIS/BAS) and self-efficacy on the affect, enjoyment and perceived exertion responses to a commonly used HIIE protocol in adolescent boys and girls. We hypothesised that individuals with high BAS, low BIS, and high self-efficacy would perceive HIIE to be more pleasurable and enjoyable, and less exertional compared to individuals with low BAS, high BIS and low-efficacy.

8.3 Methods

8.3.1 Participants

The data in the current study were obtained by combining data across two studies (Chapters 6 and 7) examining the perceptual responses to commonly used HIIE protocols in adolescents. Data on individual personality and self-efficacy in response to affect, enjoyment and RPE during HIIE were not reported in these studies. The present study resulted in the sample size of 30 participants (11 to 13-years-old, 15 boys). Written assent from the participants and written informed consent from the parent/guardian were obtained. The study procedures were granted by the Sport and Health Sciences Ethics Committee (61207/B/03 and 170712/B/02), University of Exeter.

8.3.2 Experimental overview

This study required two laboratory sessions that took place in a satellite laboratory in the school, separated by a minimum two-day rest period. The first visit was to measure anthropometric variables, determine cardiorespiratory health status and familiarise participants with the measurement scales. Participants also were asked to complete a BIS and BAS scales which consist of 20 items (Carver and White, 1994) in the first visit. This was followed by another visit involving a cycling HIIE protocol. All exercise tests were performed using an electronically braked cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands).

8.3.3 Anthropometric and physical activity measures

Stature and body mass were quantified to the nearest 0.01 m and 0.1 kg using standard procedures. 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). Cardiometabolic health status was determined based on the age and sex specific aerobic fitness cut-offs (Adegboye et al., 2011). Following completion of the HIIE protocol, 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 hours/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 MVPA using validated cut-points (Phillips et al., 2013).

8.3.4 Cardiorespiratory fitness

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

8.3.5 High-intensity interval exercise protocols

Participants completed the HIIE protocol consisting of a 3 minutes warm-up at 20 W followed by 8 x 1 minute work intervals performed at 85% of the PPO determined from the ramp test, interspersed with 75 s active recovery at 20 W (85%HIIE). A 2 minutes cool down at 20 W was provided at the end of the protocol.

8.4 Experimental measures

A detailed explanation of the affect, enjoyment and RPE measurements is presented in Chapters 5 and 6.

8.4.1 Exercise Task Self-Efficacy

Participants' confidence in their ability to repeat the HIIE protocol they just completed was assessed at 20 minutes post-exercise using a 5-item measure. Each question anchored the stem ''How confident are you that you can'' following the item ''perform one/two/three/four/five bout(s) of exercise a week for the next 4 weeks that is just like the one you completed today?'' Participants responded to each item on a 100-point percentage scale with 10 percent increments that ranged from 0% (not at all confident) to 100% (completely confident). The five item scores was averaged and used as the self-efficacy score. The format for this scale was consistent with Bandura (1997) and previous study that examined the influence of affect responses to HIIE in adult (Jung et al., 2014). Based on the Cronbach's alpha test, the internal consistencies for the self-efficacy scale in this study were excellent (α= 0.93). Self-efficacy questionnaire was administered by the same researcher.

8.4.2 Behavioural activation and behavioural inhibition

An individual's personality characteristics was measured during the first visit using the BIS and BAS scales which consist of 20 items (Carver and White, 1994). This scale has been successfully used and validated for use in adolescents (Schneider and Graham, 2009, Cooper et al., 2007). Items are scored on a four-point Likert-type scale. The BIS consists of a single subscale measuring the anticipation of punishment, whereas the BAS consists of three subscales measuring drive, fun seeking, and reward responsiveness. In order to focus on different aspects of incentive sensitivity of BAS as proposed by Carver and White (1994), the reward responsiveness subscale was used to represent the BAS group. This is because previous work in youth has shown that feelings of reward facilitated elevated enjoyment levels after HIIE (Malik et al., 2017). The total score for BAS and BIS were averaged for each item and used as the BAS and BIS score. The internal consistencies for the BIS and BAS scale in this study were excellent (α= 0.80 and α= 0.86, respectively). BIS/BAS questionnaire was administered by the same researcher.

8.5 Statistical analyses

All statistical analyses were conducted using SPSS (24.0; IBM Corporation, Armonk, NY, USA). Descriptive characteristics (mean ± standard deviation) and cardiorespiratory data between boys and girls were analysed using independent samples t-tests. The BAS/BIS and self-efficacy variables were transformed into dichotomous variables using a median split to form high and low groups for the total of 30 participants: low (n = 14) and high (n = 16) BAS; low (n = 17) and high (n = 13) BIS; and low (n = 15) and high (n = 15) self-efficacy). This median split was conducted after all the participants completed the HIIE protocol. The mean difference between median split groups was analysed using an independent sample t-test. Data were analysed using a mixed model ANOVA to examine group differences (low BAS vs. high BAS; low BIS vs. high BIS; low self-efficacy vs. high self-efficacy) in affect, enjoyment, and RPE over time during HIIE (the work and recovery intervals) and incremental test (minute 1, VT, VT+1 minute, end). The exclusion of sex into the ANOVA model was due to the insufficient numbers between boys and girls across the group following the median split. In the event of significant effects ($P<0.05$), follow-up Bonferroni post hoc test were conducted to examine the location of mean differences. The magnitude of mean differences was interpreted using 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.

8.6 Results

The participants' descriptive characteristics are presented in Table 8.1. A total of 26 participants (12 boys) were deemed to have a low level of aerobic fitness indicative of increased cardiometabolic risk. Three participants were categorised as overweight and the remainder were normal weight. Three boys and one girl achieved the recommended guideline of 60 minutes of daily MVPA.

Table 8.1 Descriptive characteristics of the participants (N = 30)

	Boys (n=15)	Girls (n=15)	P- value	ES
Age (y)	12.4 ± 0.5	12.6 ± 0.7	0.42	0.33
Body mass (kg)	44.0 ± 6.1	45.0 ± 8.7	0.71	0.13
Stature (m)	1.57 ± 0.08	1.55 ± 0.07	0.52	0.27
BMI (kg·m^{-2})	18.5 ± 2.0	19.0 ± 3.8	0.61	0.16
Body fat (%)	14.5 ± 4.3	22.7 ± 8.8	**0.003**	1.18
MVPA per day (min)	36 ± 13	30 ± 12	0.22	0.48
HR_{max} (bpm)	191 ± 6	188 ± 6	0.14	0.50
$\dot{V}O_2$ (L·min^{-1})	1.60 ± 0.24	1.57 ± 0.19	0.68	0.14
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	37.0 ± 4.7	34.1 ± 3.3	0.06	0.71
VT (L·min^{-1})	0.87 ± 0.21	0.73 ± 0.11	0.05	0.84
VT (%$\dot{V}O_{2\,max}$)	53.4 ± 10.7	46.8 ± 6.1	0.05	0.76

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.

HIIE cardiorespiratory data for boys and girls are presented in Table 8.2. Based on the VT representing ~ 50% VO_{2max}, the prescribed 85%HIIE protocol was performed at an intensity that exceeded the VT for work-intervals 1 to 8 (i.e. 71% to 78% $\dot{V}O_{2max}$). There were significant increases in HR across consecutive work intervals in all BIS/BAS and self-efficacy groups (*P*<0.01), but there was no condition by interval number interaction (all *P*>0.28) or main effect of condition (*P*>0.31). A total of 27 participants (14 girls) reached the cut-off point of ≥90 % HR_{max}, which occurred during work intervals 4 to 8. All participants completed the 85%HIIE protocol and no adverse events were observed.

Table 8.2 Cardiorespiratory responses to high-intensity interval exercise

	Mean ± SD			
	Boys	Girls	P-value	ES
Average HR (bpm)	155 ± 8	158 ± 6	0.13	0.46
Average % HRmax	81 ± 4	83 ± 3	0.06	0.85
Peak HR (bpm)	180 ± 4	182 ± 5	0.92	0.44
Peak %HRmax	94 ± 4	96 ± 3	0.16	0.57
Average $\dot{V}O_2$ (L·min^{-1})	0.98 ± 0.11	0.96 ± 0.13	0.72	0.17
Average $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	60 ± 6	61 ± 8	0.70	0.14
Peak $\dot{V}O_2$ (L·min^{-1})	1.26 ± 0.11	1.20 ± 0.12	0.11	0.52
Peak $\dot{V}O_2$ (%$\dot{V}O_{2max}$)	79 ± 10	76 ± 8	0.41	0.33

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 gas exchange.

8.6.1 BIS/BAS with affective responses

The BAS and BIS exhibited an average of 2.72 ± 1.1 (minimum to maximum=1.86 to 3.71) and 2.79 ± 0.5 (1.86 to 3.71) of total score, respectively. The BAS (low= 2.32 ± 0.7 vs. high= 3.01 ± 1.1; *P*=0.04, ES=0.74) and BIS (low= 2.14 ± 0.5 vs. high= 2.99 ± 0.9; *P*=0.03, ES=1.08) indicated a significant difference between groups. For the incremental test, FS showed a significant group by time interaction effect for BIS (*P*=0.025) and BAS (*P*=0.031) during the ramp-incremental test to exhaustion. FS was significantly higher in high compared to low BAS at VT+1 minute and end of incremental test (all P<0.021, ES=0.49 and 0.46, respectively). FS was also significantly higher during low BIS than high BIS at VT+1 minute and end (all P<0.029, ES=0.49 and 0.45, respectively). FS remained negative at the end of incremental test in low BAS in 14 participants (100%; FS= -1.5 ± 0.8), high BAS in 12 participants (75%; FS= -1.0 ± 1.3), low BIS in 13 participants (76%; FS= -1.1±1.3) and high BIS in 13 participants (100%; FS=-1.6 ± 0.9).

The affective responses during 85%HIIE when separated for BIS/BAS groups are illustrated in Figure 8.1. FS showed a significant group by interval number interaction effect for BIS (P=0.028) and BAS (P=0.039). FS was significantly higher in high compared to low BAS at work intervals 4 to 8 (all P<0.039, ES=0.59 to 1.73) and recovery intervals 4 to 7 (all P<0.031, ES=0.50 to 1.56, respectively). FS was also significantly higher during low BIS than high BIS during work intervals 4 to 8 (all P<0.012, ES=0.99 to 1.68) and recovery intervals 4 to 7 (all P<0.032, ES=1.11 to 1.48). FS remained positive at work-interval 8 in low BAS in 11 participants (78%; FS= 0.8 ± 0.7), high BAS in 16 participants (100%; FS= 2.1 ± 1.3), low BIS in 16 participants (94%; FS= 2.0 ± 1.3) and high BIS in 11 participants (84%; FS=0.12 ± 0.9). A strong negative relationship was observed between absolute HR and $\%HR_{max}$ (r=-0.85, all P <0.034) in all groups.

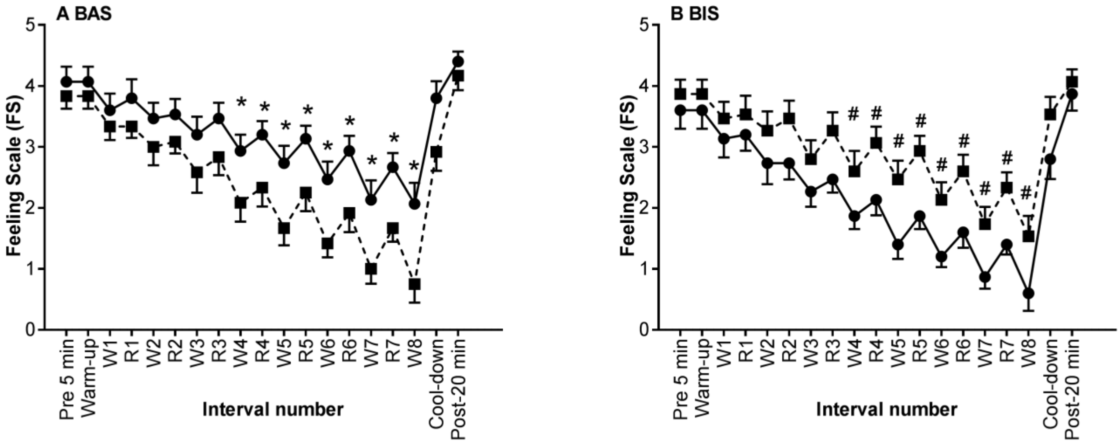

Figure 8.1 Feeling scale for behavioural activation (BAS) (A) and behavioural inhibition (BIS) (B) during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for the high (●) and low (■). Where, W= work interval and R= recovery interval. *Significant difference between high and low BAS (*P*<0.05). #Significant difference between high and low BIS (*P*<0.05). Error bars are presented as standard deviation. See text for details.

FAS did not reveal any significant group by interval number interaction for BAS (*P*=0.41) and BIS (*P*=0.26) or a main group effect for BAS *(P*=0.21) and BIS *(P*=0.28) (see Figure 8.2). Affective responses (valence and activation) during the work intervals for HIIE protocols when separated for BIS/BAS were plotted onto a circumplex model (Figure 8.3 A, B, C and D). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant for all BIS/BAS groups.

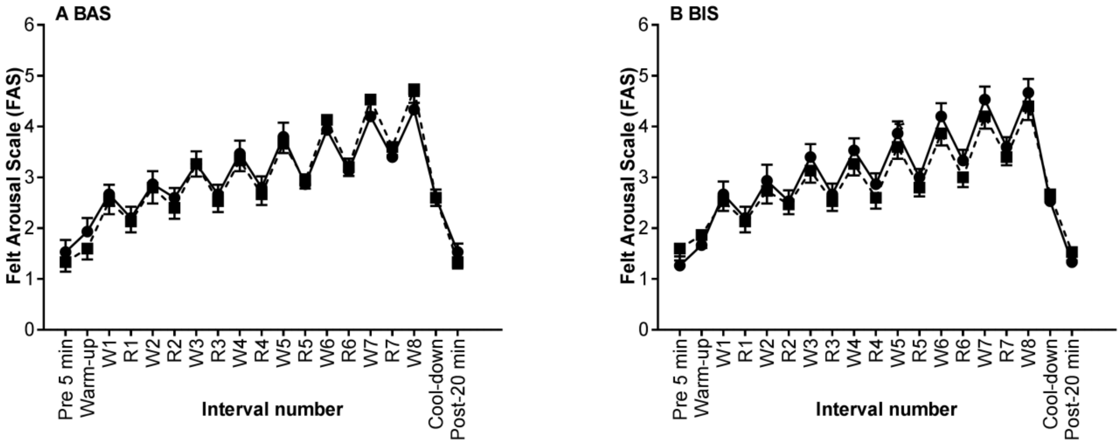

Figure 8.2 Felt arousal scale for behavioural activation (A) and behavioural inhibition (B) during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for the high (●) and low (■). Where, W= work interval and R= recovery interval. Error bars are presented as standard deviation. See text for details.

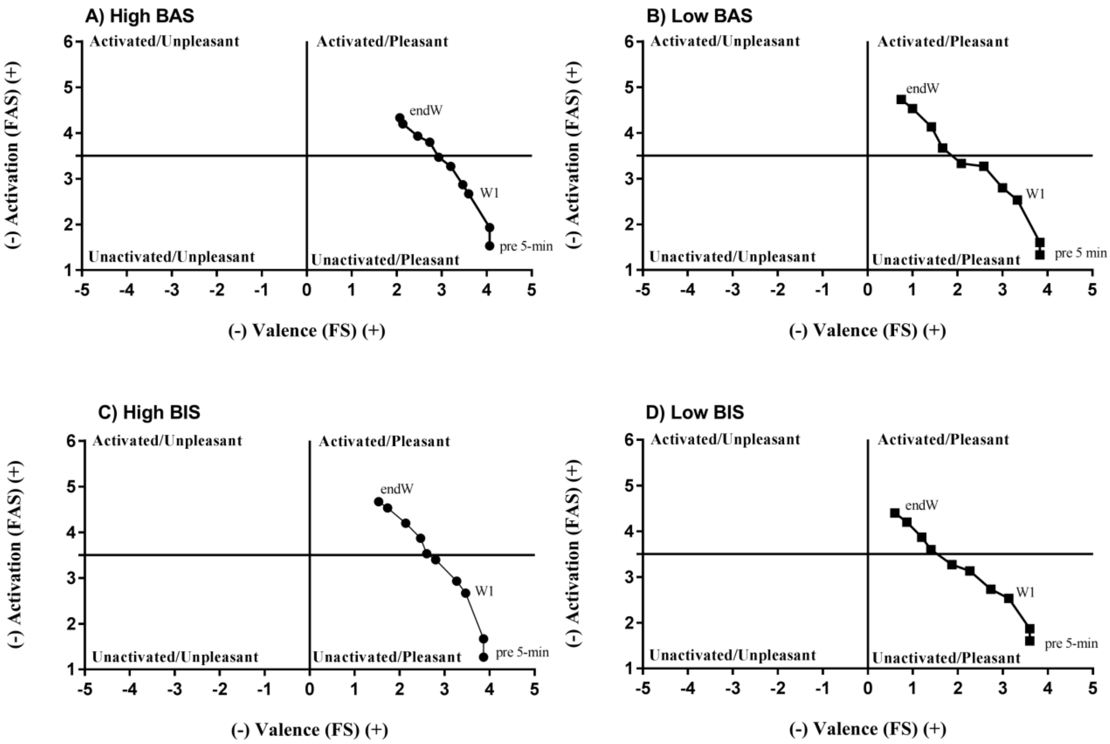

Figure 8.3 Valence (Feeling scale) and activation (Felt arousal scale) during the work interval of high behavioural activation (A), low behavioural activation (B), high behavioural inhibition (C) and low behavioural inhibition (D) plotted onto the circumplex model. Where, W= work interval and endW= work interval 8. See text for details.

8.6.2 BIS/BAS with enjoyment responses

The enjoyment responses during 85%HIIE when separated for BIS/BAS groups are illustrated in Figure 8.4. EES showed a significant group by interval number interaction effect for BAS (*P*=0.01) and BIS (*P*=0.039). EES was significantly higher in high compared to low BAS at work-intervals 5 to 8 and recovery-intervals 5 to 7 (all *P*<0.015; ES=1.21 to 1.66 and ES=1.15 to 1.16, respectively). EES was also significantly higher in low compared to high BIS at work-intervals 5 to 8 and recovery intervals 5 to 7 (all *P*<0.035; ES=1.31 to 1.86 and ES=1.18 to 1.20, respectively).

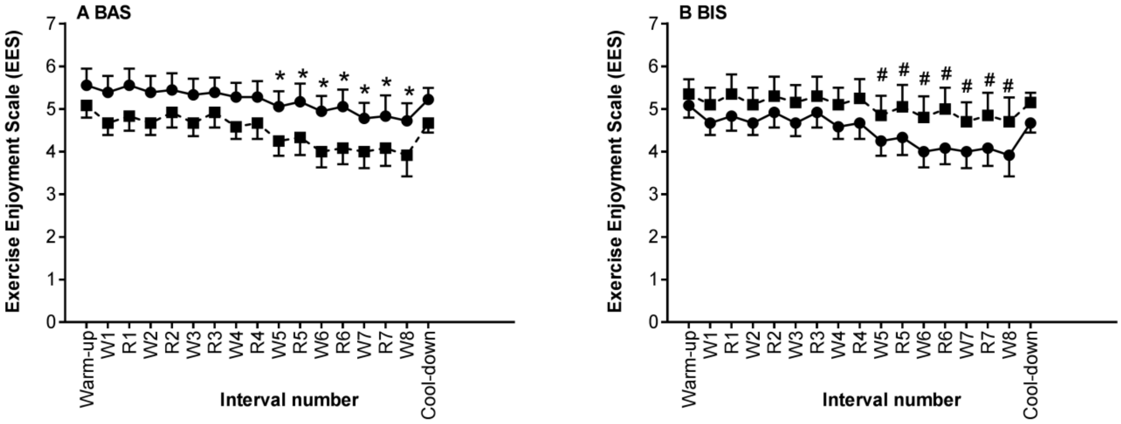

Figure 8.4 Exercise enjoyment scale for behavioural activation (BAS) (A) and behavioural inhibition (BIS) (B) during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for the high (●) and low (■). Where, W= work interval and R= recovery interval. *Significant difference between high and low BAS (*P*<0.05). $^{\#}$Significant difference between high and low BIS (*P*<0.05). Error bars are presented as standard deviation. See text for details.

PACES showed a significant main group effect in BAS (*P*=0.02) and BIS (*P*=0.038). PACES was significantly higher in high than low BAS immediately after (75 ± 3 vs. 72 ± 2, ES=1.19) and 20 minutes after 85%HIIE (77 ± 2 vs. 74 ± 2, ES=1.50). PACES was also significantly higher in low than high BIS immediately after (74 ± 4 vs. 71 ± 2, ES=0.95) and 20 minutes after 85%HIIE (75 ± 2 vs. 73 ± 2, ES=1.00).

8.6.3 BAS/BIS with rating of perceived exertion

The RPE responses during 85%HIIE when separated for BIS/BAS groups are illustrated in Figure 8.5. RPE did not revealed any significant group by interval number interaction for BAS (*P*=0.31) and BIS (*P*=0.36) or a main group effect for BAS *(P*=0.14) and BIS *(P*=0.10).

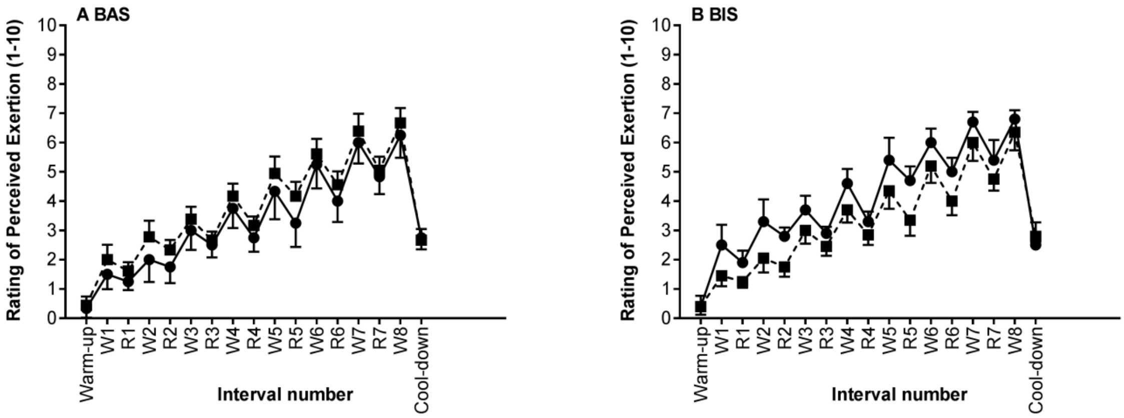

Figure 8.5 Rating of perceived exertion for behavioural activation (BAS) (A) and behavioural inhibition (BIS) (B) during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for the high (●) and low (■). Where, W= work interval and R= recovery interval. Error bars are presented as standard deviation. See text for details.

8.6.4 Self-efficacy with affective responses

The self-efficacy exhibited an average of 70 ± 18 of total score (minimum to maximum= 40 to 100). There was a significant difference between low and high self-efficacy (low= 55 ± 8 vs. high= 85 ± 10; *P*=0.032, ES= 3.31). For the incremental test, FS showed a significant group by time interaction effect in self-efficacy (*P*=0.03) during the incremental test to exhaustion. FS was significantly higher in high than low self-efficacy group at VT+1 minute and end (all *P*<0.043, ES= 0.45 and 0.50, respectively). FS remained negative at the end of incremental test in low self-efficacy in 15 participants (100%; FS= -1.6 ± 1.1) and high self-efficacy in 11 participants (73%; FS=-1.1 ± 0.9).

The affective responses during the 85%HIIE when separated for low vs. high self-efficacy are illustrated in Figure 8.6. FS exhibited a significant group by interval number interaction effect in self-efficacy (*P*=0.024). FS was significantly higher in high than low self-efficacy group during work-intervals 5 to 8 (all *P*<0.026, ES= 0.88 to 1.06) and recovery-intervals 5 to 7 (all *P*<0.042, ES= 0.79 to 0.73). FS remained positive at work-interval 8 in the high-efficacy group in 15 participants (100%; 1.7 ± 1.3) and low-efficacy group in 12 participants (80%; 0.8 ± 0.7). A strong negative relationship was observed between absolute HR and $\%HR_{max}$ (r= -0.89, all *P* <0.029) in all groups.

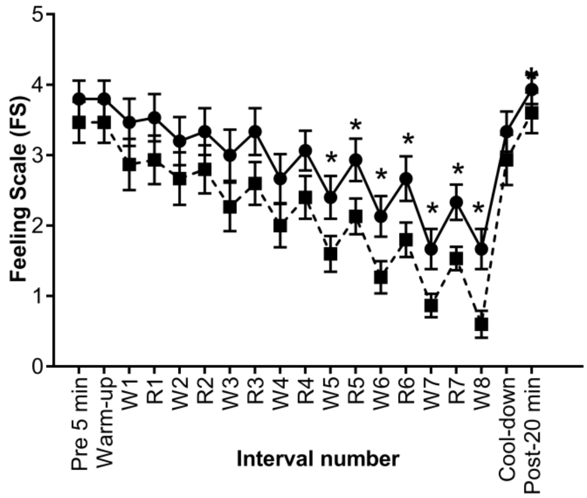

Figure 8.6 Feeling scale during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for high-efficacy (●) and low-efficacy (■). Where, W= work interval and R= recovery interval. *Significant difference between high and low self-efficacy (*P*<0.05). Error bars are presented as standard deviation. See text for details.

FAS did not reveal any significant group by interval number interaction for high self-efficacy (*P*=0.39) and low self-efficacy (*P*=0.16) or a main group effect for high self-efficacy *(P*=0.34) and low self-efficacy *(P*=0.25) (see Figure 8.7). Affective responses (valence and activation) during the work intervals for 85%HIIE protocol, when separated for self-efficacy groups, were plotted onto a circumplex model (Figure 8.8 A and B). There was a shift from the unactivated/pleasant to the activated/pleasant quadrant for all self-efficacy groups.

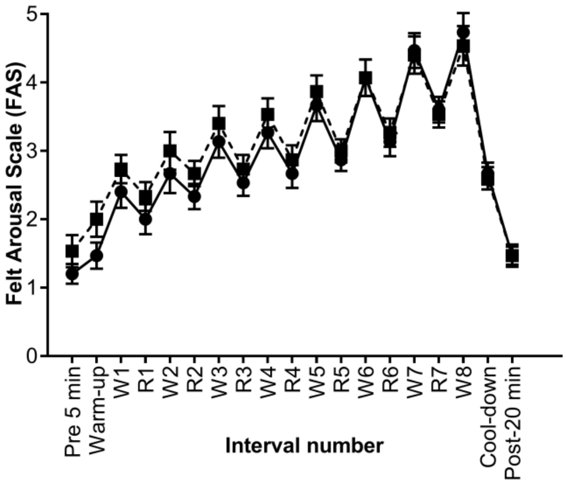

Figure 8.7 Felt arousal scale during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for high-efficacy (●) and low-efficacy (■). Where, W= work interval and R= recovery interval. Error bars are presented as standard deviation. See text for details.

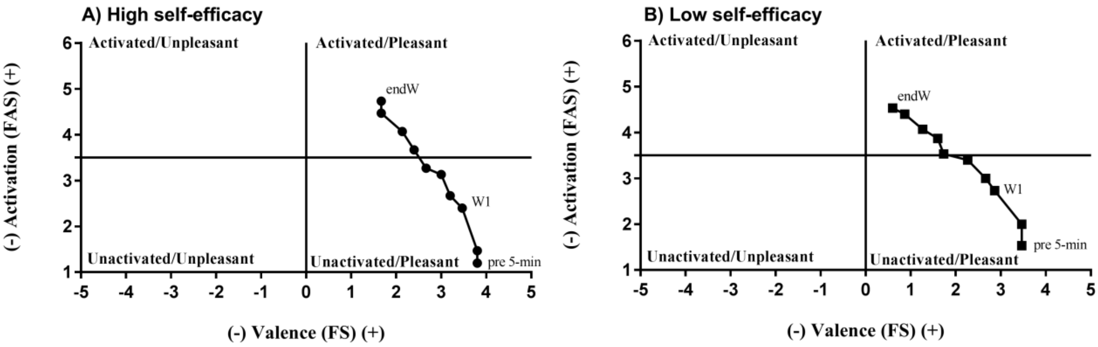

Figure 8.8 Valence (Feeling scale) and activation (Felt arousal scale) during the work interval of high self-efficacy (A) and low self-efficacy (B) plotted onto the circumplex model. Where, W= work interval and endW= work interval 8. See text for details..

8.6.5 Self-efficacy with enjoyment responses

The enjoyment responses during the 85%HIIE when separated for self-efficacy groups are illustrated in Figure 8.9. EES exhibited a significant group by interval number interaction effect in self-efficacy (*P*=0.031). EES was significantly higher in high than low self-efficacy group at work-intervals 5 to 8 (all *P*<0.044, ES=0.62 to 0.99) and at recovery-intervals 5 to 7 (all *P*<0.048, ES=0.53 to 0.89). There was no condition by time interaction (*P*=0.58) or effect of group (*P*=0.62), but there was a main effect of time (*P*<0.01) for PACES. PACES was significantly higher 20 minutes after compared to immediately after HIIE (high-efficacy, 76 ± 2 vs. 74 ± 3, *P*=0.02, ES=0.67; low-efficacy, 76 ± 3 vs. 73 ± 2, *P*=0.002, ES=1.18).

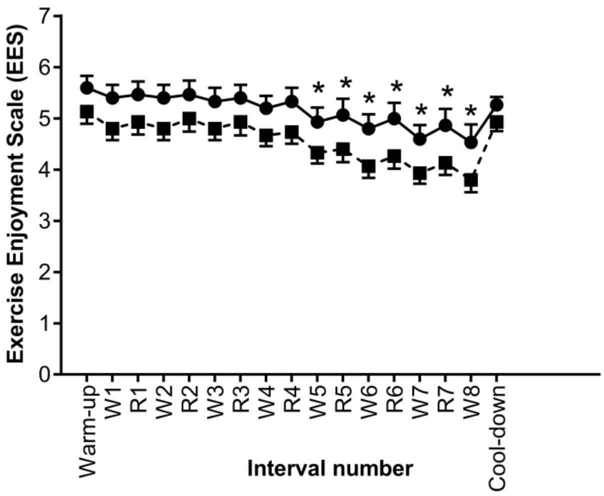

Figure 8.9 Exercise enjoyment scale during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for high-efficacy (●) and low-efficacy (■). Where, W= work interval and R= recovery interval. *Significant difference between high and low self-efficacy (*P*<0.05). Error bars are presented as standard deviation. See text for details.

8.6.6 Self-efficacy with rating of perceived exertion

The affective responses during 85%HIIE when separated for low vs. high self-efficacy are illustrated in Figure 8.10. RPE exhibited a significant group by interval number interaction effect in self-efficacy (*P*=0.018). RPE was significantly higher in high compared to low self-efficacy groups during work-intervals 5 to 8 (all *P*<0.037, ES=0.98 to 1.43).

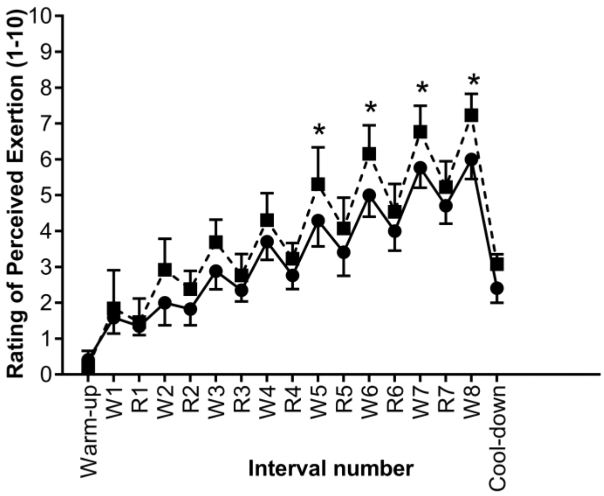

Figure 8.10 Rating of perceived exertion during the work and recovery phases of high-intensity interval exercise performed at 85% peak power for high-efficacy (●) and low-efficacy (■). Where, W= work interval and R= recovery interval. *Significant difference between high and low self-efficacy (*P*<0.05). Error bars are presented as standard deviation. See text for details.

8.7 Discussion

The aim of this investigation was to examine the role of personality characteristics (i.e. BIS/BAS) and self efficacy on affect, enjoyment and RPE responses during a commonly used HIIE protocol in adolescents. The key findings are: 1) the high BAS/low BIS group experienced greater positive affect and enjoyment responses at the mid-point to the end of the 85%HIIE bout compared to the low BAS/high BIS group; 2) the high BAS/low BIS group also experienced greater post-enjoyment (immediately after and 20 minutes after) compared to low BAS/high BIS group; and 3) the high self-efficacy group elicited greater positive affect and enjoyment accompanied by lower RPE at the mid-point to the end of the 85%HIIE bout compared to low self-efficacy group.

The DMT postulates that cognitive processes to generate positive affect during high-intensity exercise above the VT would be weak, if not entirely obscure, because of the increases in physiological cues (e.g. increased in HR) observed during this form of exercise (Ekkekakis, 2003). In the present study, we observed strong positive correlations between affect and HR responses across 85%HIIE work intervals in all group, indicating that less pleasurable feelings may be related to the physiological responses as predicted by the DMT. This observation is consistent with a previous study in youth (Malik et al., 2018b). However, here we have also observed that greater positive affect and enjoyment levels in high BAS/low BIS group than low BAS/high BIS groups during the last five work intervals. These findings suggest that BIS and BAS characteristics of the individuals may have dependent effects for about half of the 85%HIIE bout. According to the DMT (Ekkekakis, 2003), an individual's interpretation of physiological cues (e.g. pain due to the intensified physiological strain such as increased in HR) manifest in an expression of pleasant and unpleasant feelings and may be influenced by personality characteristics in the zone of response variability (i.e. exercise above the VT, termed as high-intensity). Indeed, Ekkekakis et al. (2005a) argued that the presence of stable inter-individuals traits (e.g. personality traits) can influence the intensity of exercise a person is predisposed to tolerate or select. It is therefore suggested that variation in personality characteristics (i.e. BAS/BIS) may influence an individual ability to cope with intensified physiological strain (e.g. increased in HR) that could either improve or reduce a positive affect and enjoyment experience during HIIE in youth.

In the present study, the greater positive affect and enjoyment responses in the high BAS compared to low BAS may due to the greater sensitivity to reward, which led participants to perceive the challenge of 85%HIIE as positive reinforcement as proposed by Gray's personality theory (Gray, 1991). Whereas, a greater sensitivity to punishment and threat cues may have caused high BIS individuals to perceive the challenge of 85%HIIE as a negative reinforcement, resulting in less pleasurable and enjoyment compared to low BIS individuals. In contrast to our data, Schneider and Graham (2009) stated that only BIS and not BAS influences affect during CHIE in youth. Differences in type of exercise (continuous vs interval) may be an important contributing factor to these inconsistent results. Furthermore, the high BAS group in the Schneider and Graham (2009) study experienced negative affect during CHIE, whereas the majority of our participants (above 78%), regardless of personality characteristics, evoked positive affect at the end of the HIIE bout. This observation highlights that the recovery interval built into HIIE reduced the challenge posed by the HIIE protocol, thus making this protocol better tolerated and a less threatening condition. This is consistent with the findings of Malik et al. (2018b), which indicated that the recovery intervals may not hold the prominent feelings of displeasure during HIIE.

The present study also found greater pleasurable and enjoyment feelings in the high self-efficacy group compared to the low-efficacy group during 85%HIIE. Our result is in accordance with a previously reported study in adults, which suggested that high self-efficacy individuals tend to report greater positive affect compared to low-efficacy individuals when exercise is performed at high-intensity exercise (i.e. above 70% of predicted maximal HR) during a graded exercise test (McAuley and Courneya, 1992). According to Bandura (1997), high self-efficacy individuals are more likely to engage in challenging tasks and are more resistant to stressful or aversive stimuli compared to individuals with low-efficacy. This may explain the differences in affect and enjoyment responses between the low and high self-efficacy groups during 85%HIIE in our study. These observations, however, were only evident after work interval 5, suggesting that the challenging or stressful stimuli during 85%HIIE is only perceived after about half of the total work performed. We reason that low-intensity exercise performed during recovery periods could potentially improve confidence levels even with low-efficacy group by reducing the aversive and stressful stimuli (i.e. intensified sensory body cues) found after about half of the total work is performed. It should also be noted that similar enjoyment was observed following 85%HIIE in both low and high efficacy individuals. In light of enjoyment findings from the study by Malik et al. (2017), it is possible that the participants interpreted the HIIE as a mastery experience (e.g. it gives me a strong feeling of success) regardless of levels of confidence. Indeed, Bandura (1997) has proposed that mastery experiences serve as the potent source to develop beliefs in one's personal efficacy towards the relatively risk or challenge situations compared to vicarious experience and social persuasion.

In this study, we found similar RPE regardless of personality characteristics, but high self-efficacy individuals elicited lower RPE compared to low self-efficacy individuals. This indicates that self-efficacy and personality traits have an independent effect on RPE during 85%HIIE in adolescents. We speculate that this is because self-efficacy is more associated with judgment of one's capabilities or confidence to execute a demanding task, while BIS/BAS is associated with the judgment of one's feelings regarding the exercise task. Indeed, RPE reflects the conscious sensation of how hard, heavy, and strenuous the physical task is (Pageaux, 2016). Furthermore, previous studies in adult and youth have consistently shown that personality traits do not influence RPE during continuous exercise regardless of intensity (moderate vs. high) (Schneider and Graham, 2009, Coquart et al., 2012). With regards to self-efficacy, previous studies have shown that lower RPE during exercise is linked with higher self-efficacy after exercise in youth (Robbins et al., 2004, Pender et al., 2002), which supports our observations. However, these studies (Robbins et al., 2004, Pender et al., 2002) were limited to CMIE (e.g. 60% VO_{2max}) and no observations were made regarding affect and enjoyment. In this study, the high-efficacy group reported lower RPE accompanied by greater pleasurable and enjoyment feelings compared to low-efficacy group, which supports the previous work in adults, but utilised incremental exercise (McAuley and Courneya, 1992). Our data therefore supports the proposition that self-efficacy may influence what (i.e. RPE) and how (i.e. affect) individuals feel during 85%HIIE in youth.

In the present study, we observed that at the end of incremental test to exhaustion in BIS/BAS and self-efficacy groups, more than 78% and 73% of participants, respectively, experienced negative affect responses compared to more than 75% and 80% of participants who experienced positive affect at the end of 85%HIIE bout. These observations strengthen previous work on adolescents that indicates this HIIE protocol does not elicit prominent unpleasant feelings (Malik et al., 2018b), as argued by others (Biddle & Batterham, 2015; Hardcastle et al., 2014). According to Kahneman et al. (1993), the peak (positive vs. negative) and end affect are the most important stimulus that provide overall interpretation of an exercise session (Parfitt and Hughes, 2009, Hargreaves and Stych, 2013) to predict future adherence (Rhodes & Kates 2015). Furthermore, 85%HIIE elicited affect experienced to the boundary of the activated pleasant feelings on the circumplex model in all groups (see Figure 8.3 and 8.8) due to similar arousal (measured by FAS score). Therefore, our findings reinforce the feasibility of 85%HIIE to preserve pleasurable feelings during exercise in adolescents regardless of personality characteristics and levels of self-efficacy.

The practical implication of the present study is that individual differences in personality characteristics and self-efficacy may need to be considered when prescribing HIIE interventions in youth. We observed that low BAS/high BIS groups elicited lower positive affect responses at the mid-point to the end of HIIE compared to high BAS/low BIS groups. Therefore, strategies could be adopted by educators or teachers when targeting high BIS and low self-efficacy individuals with HIIE interventions. For instance, by using the HIIE programme proposed in Chapter 4, verbal encouragement or cognitive reframing could be used by teachers to help high BIS and low self-efficacy students cope with the aversive sensations (e.g. displeasure feelings) upon the termination or the last few bouts of HIIE (e.g. intermittent running/cycling programme as highlighted in Chapters 4 to 7). Teachers could do this by encouraging the students to think of the unpleasant experiences as positive signs that one's body is getting stronger and healthier near the end of running repetitions (e.g. the last four repetitions). Other techniques such as attentional dissociation strategy (e.g. diverting attention away from the aversive stimuli by listening to self-selected music) may build positive perceptions of feelings (e.g. affect and enjoyment) and perceived ability towards the exercise. Indeed, previous studies have shown that these aforementioned strategies could improve affect and enjoyment responses during HIIE in adults, (Stork et al., 2015, Tritter et al., 2013), although yet to be explored in youth.

This study is limited to the single work intensity used to prescribed HIIE. Previous work has shown that the relationship between perceptual responses (e.g. affect and RPE) and cognitive factors (e.g. BIS/BAS and self-effficacy) should vary in magnitude as a function of exercise intensity (Hall et al., 2005). However, this is the first study that provides insight into the influence of cognitive factors on perceptual responses during HIIE in youth. The protocol used in the present study should be considered as only one of the permutations of HIIE protocols and it is not possible to extrapolate to other HIIE protocols (e.g. different work interval durations and intensities, or different modalities) due to potential differences in perceptual and physiological responses. However, we utilised a commonly used HIIE protocol, which has been shown to generate multiple health benefits in adolescents (Bond et al., 2017). Another important limitation is that HIIE protocol performed in a laboratory setting, which, may, in turn, reduce the ecological validity of affect experience to HIIE. A research design in a laboratory setting (e.g. lack of auditory, visual and social interaction) was required, so as to ensure accurate comparison of perceptual responses (i.e. affect, enjoyment and RPE) during HIIE.

8.8 Conclusion

Our study expands the understanding of the influence of cognitive factors on temporal changes in affect, enjoyment and perceived exertion during HIIE in adolescents. The present study showed that individual differences in personality and self-efficacy may decrease or increase the likelihood that a person will experience positive affective and enjoyment response to HIIE. Our findings provide advancement to the DMT by showing that cognitive factors are related to the changes in the affect responses during HIIE in youth, but are also dependent on the

HIIE work interval. The present study extends the previous finding showing that HIIE does not generate prominent feeling of displeasure (Malik et al., 2018b) despite differences in personality and self-efficacy.

CHAPTER 9: Main findings, implications, limitations, future directions and conclusion

The purpose of this chapter is to: 1) discuss how the collective work presented in the thesis contributes to the literature; 2) highlight practical implications of the work; 3) thoughtfully consider some of the methodological limitations of the research; 4) highlight some of the potential areas of future research; and finally, 5) conclude the findings of this thesis.

9.1 Key research findings

The five original research studies presented in this thesis have revealed several pertinent findings in relation to the perceptual (i.e. affect, enjoyment and perceived exertion) and physiological (i.e. cardiorespiratory and PFC oxygenation) responses to commonly used protocols of HIIE in adolescents. This has been demonstrated with adolescent boys and girls, aged 11-13 years, during laboratory-based exercise tasks. Of particular importance were: 1) the role of HIIE work intensities on the affective responses; 2) the relationship between physiological factors and the affect responses in HIIE; 3) the relationship between cognitive factors and the affect responses in HIIE; and 4) the relationship between enjoyment and the affect responses in HIIE. Collectively, the five designated studies presented in this thesis indicate five key messages regarding HIIE in youth. Firstly, HIIE generated greater enjoyment than moderate-intensity exercise regardless of whether this was delivered using continuous or interval format. Secondly, HIIE protocols do not generate prominent unpleasant feeling when the exercise intensity of the work intervals is performed below 90% of individual's maximal exercise capacity (e.g. MAS or PPO). Thirdly, HIIE generated improvement in pleasurable and enjoyment feelings when the intensity of work intervals is prescribed in decreasing manner (e.g. HIIE performed at 100% to 70% PPO). Fourthly, HIIE elicited a HR threshold above 90% of HR_{max} when the exercise intensity of the work intervals is performed above 85% of individual's maximal exercise capacity. Finally, individual differences in personality (i.e. BIS/BAS) and self-efficacy may decrease or increase the likelihood that a person will experience positive affective and enjoyment response to HIIE.

9.1.1 Role of high-intensity interval exercise work intensities on the affective responses

The premise of experimental Chapters 5 to 7 was borne out of the practical concerns of the effectiveness and implementation of HIIE as a public health strategy. The adoption of HIIE has been argued to have limited value as a public health strategy because the inherent feelings of displeasure during HIIE is likely to adversely influence the maintenance of future participation in this form of exercise (Biddle and Batterham, 2015, Hardcastle et al., 2014). This contention is based on the DMT, which predicts that exercise above the VT, termed high-intensity exercise, typically leads to unpleasant feeling (Ekkekakis et al., 2005b), as has been shown in CHIE and incremental exercise to exhaustion in youth (Benjamin et al., 2012, Stych and Parfitt, 2011). Nevertheless, evidence from adults reveals that HIIE elicited more pleasurable feelings compared to CHIE, but less (or similar) pleasurable feelings than CMIE, indicating HIIE may or may not generate negative feelings (Jung et al., 2014, Martinez et al., 2015). Before the completion of this thesis, only a single study, conducted by Thackray and colleagues (2016), had reported affect responses during

HIIE in youth, but was limited to a single work intensity (i.e. 100% of MAS) in adolescents girls. A novelty of the present thesis was to examine a relationship between affect responses during HIIE and different work intensities in adolescents, as exercise intensity is a core principle of the DMT.

The affect-intensity relationship in the DMT is currently limited to incremental and continuous exercise, which may not adequately consider the impact of interval exercise on affective responses to exercise. The work in Chapter 5 was designed to examine the temporal changes of affect responses during a commonly used model of HIIE performed at 90% of MAS, in comparison to MIIE performed at 90% of VT in adolescent boys. This design enabled the evaluation of affect responses to exercise intensity from an interval exercise perspective as previous studies typically contrast HIIE with CMIE, but the interval may be important, regardless of intensity. Indeed, the interval nature of the exercise mimics typical PA behaviour in youth compared to continuous exercise regardless of exercise intensity (e.g. Barkley et al. (2009)). Furthermore, the MIIE protocol in Chapter 5 plays a comparative role, but not CMIE, as when contrasting HIIE to CMIE, the intensity and patterning of exercise are different. The work in Chapter 5 shows for the first time that 90%HIIE elicited a greater decline (ES= 0.49 to 1.49) from the baseline (5 minutes pre) in affect responses compared to MIIE (ES= 0.34 to 0.75), but affect was significantly lower during 90%HIIE than MIIE only after work intervals 6 and remained positive at the end of the work interval (1.2 ± 2.1 on FS). This novel finding highlights that HIIE does not elicit prominent negative affect responses, as proposed by sceptics (Biddle and Batterham, 2015, Hardcastle et al., 2014) and the DMT (Ekkekakis et al., 2005b).

Nevertheless, the data presented in Chapter 5 was limited to a single HIIE work intensity in adolescent boys. As proposed by the DMT, when exercise performed at the lower end above the VT (e.g. heavy), some perceive as positive affect and some negative affect, yet in the severe domain responses are mostly negative (Ekkekakis et al., 2005b). Therefore, the work in Chapters 6 and 7 were designed to explore this notion in the context of HIIE, of which the work intensities can be span from the heavy and severe exercise intensity domains (i.e. range from 70-100% maximal exercise capacities in youth, as highlighted in Chapter 1). Chapters 6 and 7 focussed on exploring varied HIIE work intensities and work deliveries (decreasing and increasing) to affect responses in adolescent boys and girls, respectively. Chapter 6 showed that increasing the HIIE work intensity from 70-100% PPO elicits less pleasurable feelings in adolescents, with lower affect responses during 100%HIIE compared to 70%HIIE and 85%HIIE across work intervals (ES range 0.70 to 3.47). Moreover, 70%HIIE and 85%HIIE elicited similar affect responses from work intervals 1-4 and both protocols remained in positive affect at work interval 8 in more than 87% of participants (above 1 on FS), as per findings in Chapter 5. In contrast, 100%HIIE generated negative affect at work interval 8 in 87% of participants (-1.5 ± 1.4 on FS). Therefore, the work in Chapter 6 indicates that affect responses during HIIE are dependent on the intensity of the work interval and are not entirely negative (feelings of displeasure).

Chapter 7 extended upon the findings of Chapter 6 by examining whether manipulating the HIIE work intensity, by increasing (70% to 100% PPO, $HIIE_{L-H}$) or decreasing (100% to 70% PPO, $HIIE_{H-L}$) work intensity during HIIE, could alter the intensity-affect relationship. 85%HIIE was used as the ‘control’ condition that represents the constant delivery of HIIE, which was adopted in Chapter 6 and is commonplace in the HIIE literature. The $HIIE_{L-H}$ and $HIIE_{H-L}$ protocols examined in Chapter 7 also extended the protocol used in a previous investigation focussing on continuous exercise in adults (Zenko et al., 2016). Therefore, both $HIIE_{L-H}$ and $HIIE_{H-L}$ protocols advance the common concept of the constant delivery of HIIE in the youth literature. In contrast to Chapters 5 and 6, a methodological strength of this chapter was that the HIIE protocols were matched for the total (external) work performed. Indeed, differences in the total work completed could influence affective responses to exercise, potentially masking any moderating influence of exercise intensity (Blanchard et al., 2004). Chapter 7 demonstrates that 85%HIIE and $HIIE_{L-H}$ elicited similar patterns, showing a decline in affect from baseline during the later stages of the HIIE work intervals. In contrast, affect responses only declined for the initial 75% of the total work performed during $HIIE_{H-L}$ (from the baseline to work interval 6), resulting in more pleasurable feelings towards the end work intervals than the other two protocols. Therefore, Chapter 7 indicates that changes in affect responses during HIIE are not due to the work intensities per se, as the external work was matched between conditions, but also due to the delivery pattern (e.g. increasing vs. decreasing) of the HIIE work intensity.

Collectively, the work in Chapters 5-7 indicates that HIIE may not generate entirely feelings of displeasure, and that the prescription and implementation depend on the work intensity and how the intensity is delivered during exercise. These findings enhance the evidence base surrounding the exercise intensity-affect relationship to HIIE, especially in adolescent populations, reinforcing previous findings in adult populations, and extending the DMT in an interval exercise perspectives which are performed below and above the VT. Previous studies in youth have established the independent changes of affect responses during continuous and incremental exercise below (moderate intensity domain) and above the VT (heavy and severe intensity domain) to support the DMT (Benjamin et al., 2012, Stych and Parfitt, 2011). However, the influence of temporal changes of affective responses involving a combination of two different exercise intensities (low and high intensity) within the same exercise bout, such as HIIE, is unknown.

Based on the magnitude changes of affect responses during HIIE work intervals exhibited in Chapters 5-7, two distinct phases can be identified in this thesis, namely, the 'preservation' (II) and 'deterioration' phases (III) (see Figure 9.1). In the preservation phase, affect responses were similar in the initial four work intervals performed during MIIE and 70-90% of PPO/MAS. In contrast, in the deterioration phase, the differences of affect experienced between exercise intensities were evident from work intervals 5-8. Although no direct comparison was made between each HIIE protocol in Chapters 5-7, this notion is strengthened based on the similar and different FS responses observed between 90%HIIE and MIIE (Chapter 5), and 70%HIIE and 85%HIIE (Chapter 6 and 7) during the initial (1-4) and later (> 5) stages of work intervals, respectively. The preservation phase is also characterised by a moderate decline (from the baseline, ES range = 0.30-0.66) and greater positive affect (FS range = 4-2), whereas the deterioration period is characterised by a greater decline (from the baseline, ES range = 0.86-1.49) and lower affect (FS range = 3-0). Still, both phases remained in positive affect responses (above 0 on FS).

Nevertheless, two HIIE conditions (i.e. $HIIE_{H-L}$ and 100%HIIE) did not fit this pattern of preservation and deterioration observed during MIIE and HIIE at 70-90% of PPO/MAS. Specifically, as the work intensity increases above 90% of maximal exercise capacity (PPO/MAS), there is a greater decline from the baseline (ES =

2.50), as well as lower positive affect (below 2 on FS) at the onset of work interval 1, and affect responses become negative at the later stage of work intervals (5-8), as has been shown during 100%HIIE (i.e. below -1 on FS). This suggests that the 100%HIIE protocol diminishes the existence of a ‘preservation’ phase and are characterised by a ‘deterioration’ phase. This notion is reinforced based on a significantly lower FS responses observed between 100%HIIE and 70%HIIE/85%HIIE across all the work intervals (ES range= 0.70-3.47). In contrast, $HIIE_{H-L}$ elicited lower positive affect responses during the initial work intervals (preservation phase) compared to $HIIE_{L-H}$ and 85%HIIE (ES range= 0.96-1.75), but improved to more positive affect responses near the end of work intervals (deterioration phase, ES range= 0.87 to 1.67). This finding shows that the characteristics of the preservation and deterioration phases are reversible during a decreasing pattern of HIIE. This pattern may be important for future exercise adherence as improvements in pleasurable feelings over time, and during exercise, strongly influence retrospective evaluations of the exercise experience (Ariely and Zauberman, 2003, Zauberman et al., 2006). Collectively, the work in Chapters 5-7 demonstrates that work intensity may not entirely influence affect responses during HIIE, and above the 90% of maximal exercise capacity mark is a detrimental threshold during HIIE. Also, the delivery pattern of HIIE work intervals may alter the direction of preservation and deterioration phases.

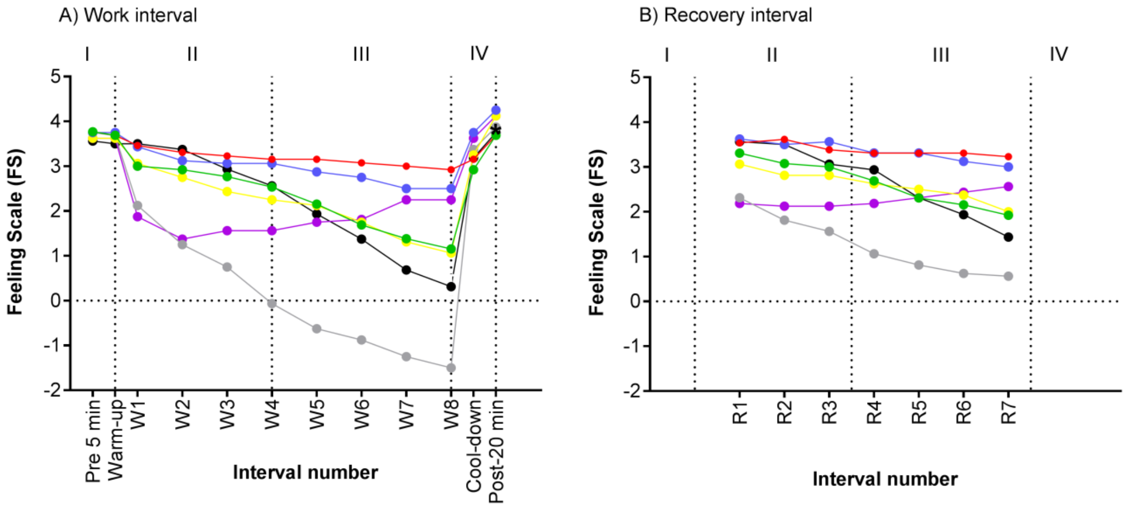

Figure 9.1 Baseline (I), preservation phase (II), and deterioration phase (III) for the feeling scale responses during the work (A) and recovery intervals (B) of moderate-intensity interval exercise (MIIE; red), high-intensity interval exercise performed at 70% peak power (70%HIIE, blue), 85% peak power (85%HIIE; yellow), 90% maximal aerobic speed (90%HIIE; green), 100% peak power (100%HIIE; grey), high-to-low peak power ($HIIE_{H-L}$; purple), and low-to-high peak power ($HIIE_{L-H}$; black). Where, W= work interval, R= recovery interval and IV= post-exercise.

One plausible explanation for the preservation and deterioration phases occurring during the work intervals may be attributed to the role of recovery intervals performed during the HIIE bout. According to the rebound theory model (Bixby et al., 2001), pleasurable feelings can occur during recovery periods (i.e. low-intensity exercise) after an unpleasant stimulus or stress generated during work stimulus (i.e. high-intensity exercise). This notion is reinforced by more positive affect during recovery intervals compared to work intervals across all HIIE conditions (including MIIE), as observed in Chapters 5-7 (see Figure 9.1 B). These findings suggest that recovery intervals are capable of preserving the affect responses for about half of the total work performed during HIIE, as has been shown in the preservation phase.

Although the deterioration phase is characterised by a greater decline and lower affect responses compared to the preservation phase, the positive affect responses, indicated by positive FS scores during this later stage of work intervals, suggest that recovery intervals may prevent further decline in affect responses. However, if the exercise intensity is too high (i.e. 100%HIIE), the recovery periods may not be able to prevent further decline in affect responses as 100%HIIE elicited lower affect responses during recovery intervals (score below 2 on FS) compared to HIIE performed below 90% of PPO/MAS (score above 2 on FS). Although FS responses remained positive for the initial 4 work intervals in 100%HIIE (above 0 on FS), the consistently lower positive affect responses across the work and recovery intervals lead to an entirely deterioration phase. Indeed, Parfitt and Eston (1995) revealed that the work stimulus (i.e. exercise intensity) may not be sufficient to generate negative feelings that at early stages of high-intensity exercise bout, but the reduction in the affect responses continues until completion of the exercise. Nevertheless, affect responses during $HIIE_{H-L}$ recovery intervals in the preservation phase were low initially (remained in 2 on FS), but started to improve in the deterioration phase (above 2 on FS). Also, the positive affect responses elicited during $HIIE_{L-H}$ in the deterioration phase is likely to be explained by the considerably higher recovery interval affect (above 2 on FS) for about 85% of total work performed. Therefore, the work in this thesis demonstrates that the recovery interval periods built into HIIE could potentially decrease the experience of psychologically aversive affect during HIIE, at intensity below the 90% of maximal exercise capacity, $HIIE_{H-L}$ and $HIIE_{L-H}$.

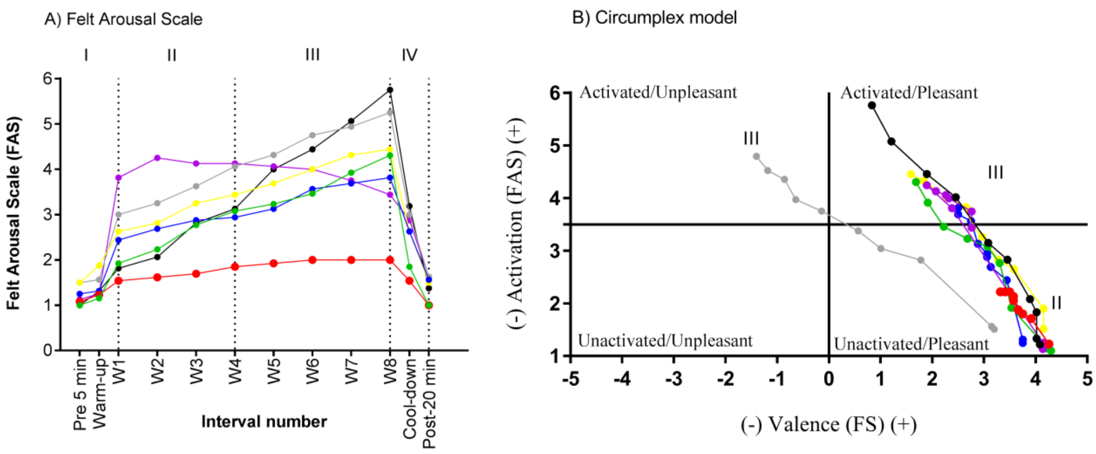

Figure 9.2 Baseline (I), preservation phase (II), and deterioration phase (III) for the felt arousal scale responses (A) and circumplex model (B) of moderate-intensity interval exercise (MIIE; red), high-intensity interval exercise performed at 70% peak power (70%HIIE, blue), 85% peak power (85%HIIE; yellow), 90% maximal aerobic speed (90%HIIE; green), 100% peak power (100%HIIE; grey), high-to-low peak power ($HIIE_{H-L}$; purple), and low-to-high peak power ($HIIE_{L-H}$; black). Where, W= work interval, R= recovery interval and IV= post-exercise.

The work in Chapters 5-7 also reveal that the perceived activation (arousal) responses were comparable across all HIIE work intervals at 70-90% PPO/MAS (see Figure 9.2 A), indicating that these work intensities generate similar activation responses in both preservation and deteroriation phases. These observations may explain the similar changes in affect responses during these intensities in the circumplex model; of which, affective responses moved from the unactivated-pleasant quadrant (i.e. evoking a sense of calmness and relaxation) and ended in the pleasant-activated quadrant (i.e. evoking a sense of excitement, enthusiasm, and happiness; see Figure 9.2 B). However, 100%HIIE elicited a greater increase in activation (ES = 1.51-3.59) compared to 70%HIIE and 85%HIIE (ES range= 1.29-

2.95) across all the work intervals. Consequently, the greater perceived activation, accompanied by a decline in affect in 100%HIIE, may contribute to the diminishing effect of the preservation phase and is likely to account for the feelings of distress and tension for about 50% of total work intervals observed in the circumplex model. This notion is reinforced by an increase in activation responses from work intervals 1 to 8 in all HIIE conditions, accompanied by a decrease in affective valence in all HIIE conditions observed in Chapters 5-7. Thus, it appears that work intensity above 90% of maximal exercise capacity may lead to progressively higher activation and progressively less positive affect in the preservation and deterioration phases of HIIE. This is in line with Hall et al. (2002), who reported that the greater increase in activation was coupled with a marked shift towards less pleasurable feelings during CHIE in adults. In contrast, $HIIE_{H-L}$ generates progressively lower activation and greater positive affect from preservation to deterioration phases, which leads to feelings of excitement in about 80% of total work intervals observed in the circumplex model. Therefore, it seems plausible to suggest that the changes in perceived activation may be a function of the overall exercise intensity during HIIE, perceived to be pleasant or unpleasant in both preservation and deterioration phases.

9.1.2 Relationship between physiological factors and affect responses in high-intensity interval exercise

The distinctive characteristics of affect responses during the preservation and deterioration phases of HIIE may be further explained via the changes in HR responses across the work intervals. The work in Chapter 4 was initially conducted to establish interval-by-interval quantification of the HR responses during HIIE (i.e. 90% PPO). These responses can demonstrate participant compliance with the HIIE protocol to improve cardiometabolic and fitness health adaptation in youth, using a predefined threshold of ≥90 HR_{max} (Taylor et al., 2015). Chapter 4 indicates that the cut-off point of ≥90% HR_{max} was reached at work interval 5 and drifted upwards until HR reached 91-98% HR_{max} during work interval 8 in the majority of adolescent boys and girls (~90%). Similarly, the work in Chapters 5-7 reveal that ≥90% of HR_{max} was attained typically at work interval 4 and continued to increase until work interval 8 during HIIE (i.e. 85%HIIE, 90%HIIE, $HIIE_{H-L}$ and $HIIE_{L-H}$) in more than 80% of adolescents. Therefore, it appears that ≥90% HR_{max} threshold is attained at the later stages of HIIE work intervals in most adolescents, as has been shown by a previous fidelity study that examined HR on an interval by interval basis during HIIE in adolescents (Taylor et al., 2015). Nevertheless, 100%HIIE generated ≥90% of HR_{max} much earlier (from work intervals 3 to 8) and 70%HIIE insufficiently generated the HR_{max} (only one participants reached ≥90% HR_{max}). This thesis demonstrates that to achieve maximal cardiorespiratory response during HIIE, the work intensity needs to perform above 85% of PPO/MAS or perform using $HIIE_{H-L}$ and $HIIE_{L-H}$ protocols.

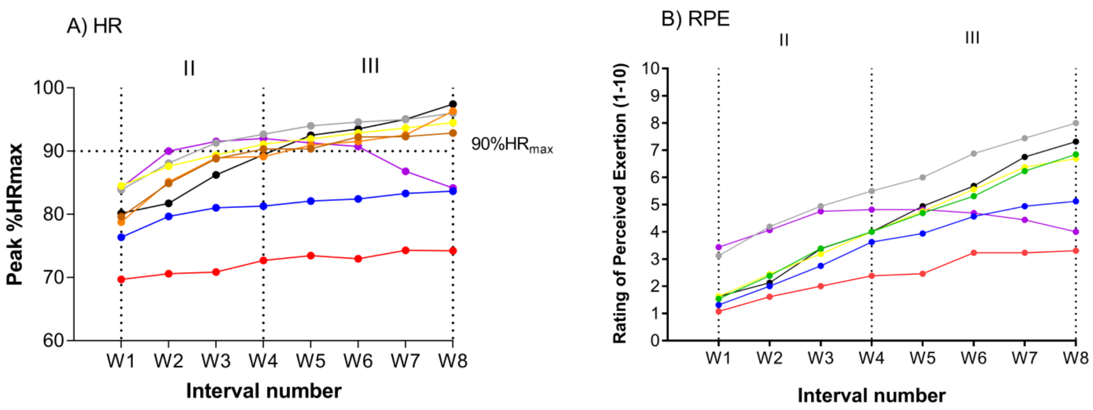

Figure 9.3 Preservation phase (II), and deterioration phase (III) for the percentage of maximal heart rate (A) and rating of perceived exertion (B) of moderate-intensity interval exercise (MIIE; red), high-intensity interval exercise performed at 70% peak power (70%HIIE, blue), 85% peak power (85%HIIE; yellow), 90% maximal aerobic speed (90%HIIE; green), 90% peak power (90%HIIE; orange), 100% peak power (100%HIIE; grey), high-to-low peak power ($HIIE_{H-L}$; purple), and low-to-high peak power ($HIIE_{L-H}$; black). Where, W= work interval and IV= post-exercise

The fundamental assumption of the DMT is that human performance is subject to certain physiological constraints (e.g. metabolic strain, HR responses) (Ekkekakis et al., 2005b). Thus, feelings of displeasure represent an ‘alarming’ function to this physiological constraint, which, much like burning/pain, is aimed to withdraw the individual from the activity that is causing danger. Given that HR responses drifted upwards across the HIIE work intervals in Chapters 4-7, affect responses may progressively become less pleasurable until the end of the HIIE bout. This notion is strengthened by the strong negative correlation between affect and HR responses across all HIIE protocols, as observed in Chapters 5-7 (r range =-0.81 to -0.98). Integration between affect and HR responses during HIIE could be explained via the distinctive phases of preservation and deterioration. Considerably low HR responses (<90% HR_{max}) and high HR responses (≥90% HR_{max}) during the preservation and deterioration phases may result in greater and lower positive affect responses during HIIE, respectively. However, the effect is reversible during the $HIIE_{H\text{-}L}$ protocol. Furthermore, the existence of a deterioration phase throughout the 100%HIIE protocol is likely to account for the high HR responses (≥90% HR_{max}) generated for about 64% of the total work intervals performed. Therefore, the differences in affect responses between preservation and deterioration phases during the HIIE protocols exhibited in Chapters 5-7 is likely to account for the changes of HR responses generated during HIIE.

Nevertheless, Oliveira et al. (2015) also reported that RPE was a better predictor of the affective responses during high-intensity exercise compared to physiological responses (e.g. HR and $\dot{V}O_2$). This thesis reinforces this notion by showing low affect responses across 100%HIIE compared to other HIIE protocols (70%HIIE, 85%HIIE, and 90%HIIE), accompanied by a greater RPE across work intervals. It seems plausible to suggest that the changes in affective responses during HIIE above 90% of maximal exercise capacity (i.e. 100%HIIE) is not only related to physiological factors (i.e. increase in HR), but also due to greater exertional stress (i.e. feelings of physical stress and fatigue). Indeed, Oliveira et al. (2015) argued that both RPE and affect responses require similar conscious processing to be generated during the HIIE performed at 100% of $\dot{V}O_2$, as both factors seems to influence the metabolic strain (e.g. increase in HR) during severe exercise.

The DMT predicts that the reduced positive affect during high-intensity exercise is caused by decreased activity in the PFC, and corresponding increased activity in the subcortical area is driven by intensified interoceptive cues, such as HR responses (Ekkekakis and Acevedo, 2006). The decline in PFC activity typically occurs during severe intensity exercise (above the RCP), and is associated with reduced oxygen availability due to decreases in cerebral blood flow (Bhambhani et al., 2007; Rooks et al., 2010). The decline in PFC oxygenation can be indicated by a lower ΔO_2Hb and higher ΔHHb measured using NIRS (Ekkekakis and Acevedo, 2006; Tempest et al., 2014). The work in Chapter 7 was carried out to address this potential mechanistic pathway underlying HIIE-induced affective responses during 85%HIIE, $HIIE_{H-L}$, and $HIIE_{L-H}$. Findings from Chapter 7 reveal that changes in PFC oxygenation are associated with affect responses to HIIE during the deterioration phase. This observation is further supported by the significant correlation between affect with ΔO_2Hb (positive), TOI (positive) and ΔHHb (negative), at the end of work intervals in all HIIE conditions. It seems plausible to suggest that the increase or decrease in PFC oxygenation during HIIE may typically occur during the deterioration phase and not during the preservation phase, regardless of work intensity or work delivery. Therefore, HR responses elicited during the preservation phase may not sufficiently trigger the (subcortical) areas of the brain responsible for the internal regulations (pain and aches). Consequently, HIIE elicits prominent positive affect responses during the preservation phase at any work intensity compared to the deterioration phase. This notion is strengthened based on the similar PFC haemodynamics exhibited during the initial 75% of HIIE work intervals (work intervals 1-6) performed at 70-100% PPO. Although the changes in PFC was not determined in Chapters 5 and 6, the wide range of work intensities in the decreasing and increasing patterns of HIIE could represent the potential association between affect responses and PFC in these two chapters. Therefore, this thesis demonstrates that greater HR responses at the later stages of the deterioration phase could reduce the PFC oxygenation by about 20% (work intervals 7 and 8) of total work performed, and may not entirely influence the affect responses during HIIE.

9.1.3 Relationship between cognitive factors and affect responses in high-intensity interval exercise

The DMT also postulates that the ability of cognitive processes (e.g. self-efficacy and personality traits) to generate positive affect during high-intensity exercise (above the VT) would be weak, if not entirely obscure, due to the decrease in PFC activity. Chapter 8 built upon this hypothesis and aimed to elucidate the influence of personality traits (BAS and BIS) and self-efficacy on affect responses during HIIE (i.e. 85%HIIE) in adolescents. Findings from Chapter 8 showed that high BAS/low BIS groups elicited greater affect compared to low BAS/high BIS groups during work intervals 5 to 8 (ES>0.59). Affect responses were also greater in high compared to low self-efficacy groups during work intervals 5 to 8 (ES>0.62).

Collectively, these observations provide additional distinct characteristics between the preservation and deterioration phases of HIIE, indicating that an individual's personality traits and self-efficacy have dependent effects on affect responses during the deterioration phase. Given that a similar pattern of affect responses was observed across HIIE performed at 70-90% PPO/MAS, it seems appropriate to suggest that the changes in affect responses during the deterioration phase of HIIE do not solely depend on the physiological factors per se, but also an individual's cognitive factors. Consequently, the ability to tolerate metabolic strain (i.e. HR responses) during the deterioration phase may depend on an individual's personality and self-efficacy. This is in line with Rose and Parfitt (2007), who argued that the interaction of an individual's cognitive and physiological factors could influence perceptions that either maintain or enhance the positive affective response during continuous exercise at a given intensity in adult women. The work in Chapter 8 extends this notion during HIIE, particularly in youth. However, it is important to note that the role of cognitive and physiological factors during HIIE using work intervals above 90% of maximal exercise capacity remains unclear. It is possible that as exercise increases above 90% of maximal exercise capacity, both factors may have a diminishing influence over affective responses to exercise, as proposed by the DMT.

9.1.4 Relationship between enjoyment and affect responses in high-intensity interval exercise

Research in youth has established that HIIE generates greater (or similar) post-enjoyment compared to CMIE, suggesting that HIIE can act as an alternative health strategy to promote health in adolescents (Bond et al., 2015a, Cockcroft et al., 2015). However, the association between affect and enjoyment were not addressed to reinforce the adoption of HIIE, to improve the health and well-being of youth. Although enjoyment is not an explicit consideration within the DMT, evidence has indicated that perceived enjoyment generated after an exercise session seems to play a role in interpretation of positive affect during continuous exercise (Raedeke, 2007). While positive affect during PA could promote adoption in future exercise behaviour (Rhodes and Kates, 2015), greater enjoyment could lead to an increase in PA, as feelings of enjoyment function as an immediate reward for being physically active (Dishman et al., 2005).

Chapters 4-7 of this thesis demonstrated perceived enjoyment responses during and after a single bout of CMIE, MIIE and HIIE in adolescents, and their association with affect responses. The initial work in Chapter 4 was to elucidate the factors that lead to greater enjoyment after HIIE compared to CMIE, through analyses of the total and individual items of the PACES. This study shows for the first time that greater enjoyment after HIIE was due to items related to feelings of reward, excitement and success. In contrast, low scores in PACES after CMIE was due to items related to feelings of boredom. Chapter 5 extended upon findings from Chapter 4 by elucidating the enjoyment responses during and after HIIE and MIIE protocols in adolescents. The comparison between interval exercises is important given that the interval nature of the exercise mimics typical PA behaviour in youth (e.g. Barkley et al. (2009). Furthermore, documenting the dynamic changes of enjoyment during HIIE may discriminate the pathway leading to post-exercise feelings (Van Landuyt et al., 2000). Chapter 5 indicates that HIIE elicited greater post-exercise enjoyment compared to MIIE (ES = 0.47), but no enjoyment differences were evident during HIIE and MIIE. Similar to Chapter 4, greater enjoyment after HIIE was due to greater scores in the items related to feelings of excitement and success, whereas MIIE was due to greater scores in items related to feelings of boredom. This finding reinforces the notion that HIIE may serve as an alternative strategy to moderate-intensity exercise to promote health in youth.

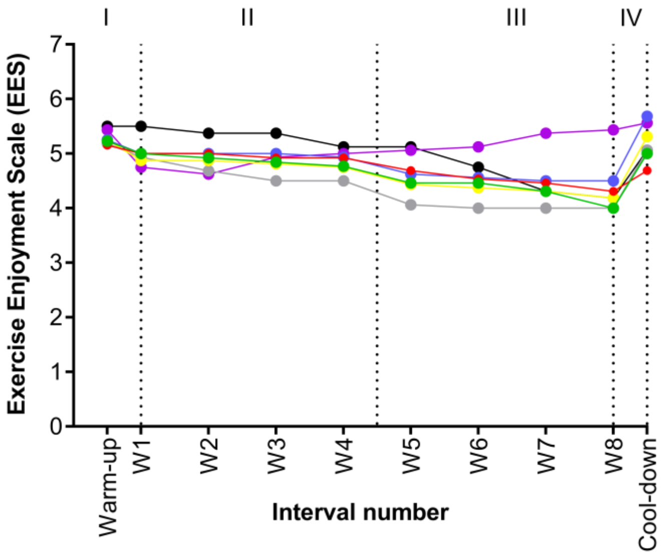

Figure 9.4 Baseline (I), preservation phase (II), and deterioration phase (III) for the exercise enjoyment scale of moderate-intensity interval exercise (MIIE; red), high-intensity interval exercise performed at 70% peak power (70%HIIE, blue), 85% peak power (85%HIIE; yellow), 90% maximal aerobic speed (90%HIIE; green), 100% peak power (100%HIIE; grey), high-to-low peak power ($HIIE_{H-L}$; purple), and low-to-high peak power ($HIIE_{L-H}$; black). Where, W= work interval, R= recovery interval and IV= post-exercise.

The work in Chapter 5 also shows for the first time a strong positive correlation between enjoyment and affective responses during exercise in 90%HIIE (r=0.97) and MIIE (r=0.86), suggesting that affect responses during interval exercise may be influenced by the enjoyment changes during exercise. Chapters 6-7 extend this finding by showing a strong positive correlation (r>0.90) between ESS and the FS responses for all HIIE conditions with different work intensities (i.e. 70%HIIE, 85%HIIE, 100%HIIE, $HIIE_{H-L}$ and $HIIE_{L-H}$). Although no enjoyment differences were observed during HIIE performed at 70-100% of maximal exercise capacity, there is a significant decline in enjoyment from the baseline at work intervals 5-8 during 70%HIIE, 85%HIIE, 90%HIIE (ES range= 0.40 to 0.52), and at work intervals 3-8 during 100%HIIE (ES=0.47 to 1.00). These observations complement the changes in affect responses during the preservation and deterioration phases, indicating that a greater decline and less positive affect in the deterioration phase compared to the preservation phase is likely to account for the decline in enjoyment responses. In contrast, $HIIE_{H-L}$ (decreasing protocol) generated lower and greater enjoyment compared to $HIIE_{L-H}$ (increasing protocol) in preservation (work intervals 1-2) and deterioration phases (work interval 8), respectively. This finding appears to suggest that changes in enjoyment responses during exercise are dependent on the work delivery, but not on the work intensity of HIIE. One plausible explanation for no significant differences in exercise enjoyment regardless of HIIE work intensity could be attributed to distinctions between affect and enjoyment. Indeed, affect only represents general feelings that are independent of the cognitive process, whereas enjoyment (emotional experience) is elicited after a cognitive appraisal process during which a stimulus (i.e. exercise intensity) is recognised as either beneficial or detrimental to the person. Consequently, during decreasing HIIE, it is possible that cognitive evaluative factors, such as a mastery component of the experience (e.g. challenging to less challenging), would aid in determining the level of enjoyment.

The work in Chapters 5-7 also indicates similar post-enjoyment responses regardless of work intensities and work delivery. As discussed above, the greater enjoyment after HIIE is due to the elevated feelings of excitement and success. A similar post-exercise enjoyment across all HIIE protocols may be attributed to the comparable challenge posed by HIIE regardless of work intensity. Indeed, enjoyment to PA in youth has been linked to the perceived success once they can succeed at experiences they find challenging (Martens, 1996). Furthermore, the work in Chapters 5-7 reveals positive correlations between the affect and post-exercise enjoyment at work interval 8 following HIIE that elicited positive affect (i.e. 70%HIIE, 85%HIIE, and $HIIE_{H-L}$). Therefore, it is plausible to suggest that affect responses elicited during the deterioration phase are crucial, as they link to post-enjoyment responses. This thesis reinforces the notion that a positive affective response experienced during exercise may lead to greater enjoyment of an exercise session, particularly in adolescents.

9.2 Implications of the current research

This thesis represents an attempt to advance the discourse beyond the ongoing debate on the adoption and maintenance of HIIE in youth, based on the DMT. The designated studies in this thesis reinforce the idea of compromise between the ideal physiological prescription and a feasible behavioural prescription. Each of the studies provides an attempt to develop an HIIE prescription that targets the promotion of pleasure and enjoyment as a central consideration (Chapters 5-8) alongside the effectiveness of each exercise condition to promote health benefits through the examination of the HR responses (Chapters 4-7). The preservation and deterioration phases of HIIE that have been identified, based on the changes in affect responses accompanied by the changes in other factors (physiological, psychological and enjoyment), could provide further implications to the application of HIIE to promote health in adolescents.

Both preservation and deterioration phases could infer the pathway of the occurrence of the peak (positive vs. negative), and end affect responses during the HIIE. This is important from the behavioural perspective, as these factors are the most consequential stimulus for affect responses during exercise (Fredrickson & Kahneman, 1993), and both are representative of the overall interpretation of an exercise session (Parfitt & Hughes, 2009; Hargreaves & Stych, 2013) to predict future adherence (Rhodes & Kates 2015). In relation to exercise, Hargreaves and Stych (2013) stated that a low peak relates to the most negative or least positive affect experienced and a high peak relates to the most positive or least negative affect experienced. In this thesis (Chapters 5-7), the low peak and end affect during HIIE, performed at 70-90% PPO/MAS, remained positive in the deterioration phase, which is likely to account for the greater positive high peak affect in the preservation phase. In contrast, less positive high peak affect in the preservation phase during 100%HIIE may lead to negative low peak and end affect. Indeed, end affect could be the most intense affective experience of the whole exercise experience, and therefore, also represent the affect peak (Hargreaves and Stych, 2013). However, $HIIE_{H-L}$ may initially elicit low peak in the preservation phase, and improve to more positive high peak and end affect in the deterioration phase.

It seems plausible to suggest that HR, affect and enjoyment responses during the deterioration phase of HIIE are pertinent, as they may have implications for health and behavioural perspectives. This thesis demonstrates that HIIE performed at 85-100% of maximal exercise capacity elicited a maximal cardiorespiratory response, based on the cut-off point of ≥90% HR_{max} in the majority (above 80%) of adolescents in the deterioration phase. Evidence has shown that ≥90% HR_{max} may serve as the criterion for compliance with the HIIE protocol to improve cardiometabolic and fitness health adaptation in youth (Taylor et al., 2015). Implications for using HIIE performed at 100%HIIE must be taken with caution, however, as this protocol generated unpleasant feelings during the deterioration phase, which could lead to avoidance of this protocol in the future. Although 70%HIIE elicited pleasurable feelings during the deterioration phase, this protocol may not be able to generate sufficient HR stimulus to facilitate sufficient health benefits. Consequently, HIIE performed at 85-90% of PPO/MAS could serve better exercise implementation and adoption, considering the positive affect experienced and enjoyment levels in the deterioration phase. However, $HIIE_{H-L}$ could offer advancement to 85%-90% HIIE protocols due to the improvement in pleasurable and enjoyment feelings elicited during the deterioration phase. Moreover, $HIIE_{H-L}$ elicited sufficient increases in HR_{max} in more than 75% of participants during the deterioration phase. This indicates that $HIIE_{H-L}$ could potentially generate multiple health benefits in adolescents. However, it is important to highlight that the effect of $HIIE_{H-L}$ on health benefits, in youth, is still to be examined.

Given the importance of both the preservation and deterioration phases of HIIE to generate favourable perceptual and physiological responses in adolescents, this thesis offers a useful approach to teachers/exercise professionals to prescribe and monitor HIIE, particularly in school-based interventions (e.g. intermittent running exercise, skipping and jumping jacks). A detailed example of the HIIE programme is presented in Chapters 4 to 7. Briefly, the work from this thesis recommends that the HIIE protocol should initially generate ‘good’ feelings (between +4 and +2 on FS) (preservation phase), and will be perceived as fairly good (between +1 and +2 on FS) by the end of the exercise (deterioration phase) (see Chapters 5 and 6 for the details). Alternatively, HIIE protocols could also generate ‘fairly good’ (0 to +1 on FS) during the preservation phase (initial four repititions) but should be perceived as ‘good’ (+3 to +4 on FS) during the deterioration phase (see Chapter 7). These guidelines are pertinent to make sure that the prescribed HIIE protocols evoke pleasurable feelings in both phases. This process can be aided via monitoring the HR and RPE responses during the preservation and deterioration phases. HIIE protocols should evoke 'getting more tired' (RPE 3-5) during the preservation phase, and will be perceived as 'tired' (RPE 6-7) at the later stage of the deterioration phase, with the associated HR response corresponding to ~82–86% HR_{max} and ~93–97% HR_{max}, respectively (see Chapters 5 and 6 for details). However, HIIE protocol that evokes 'getting more tired' to 'tired' on the RPE (3-6) scale (HR responses corresponding to 90% to 93% HR_{max}) during the preservation phase should elicit 'getting more tired to a little tired' on the RPE (4-3) scale (HR responses corresponding to 85%-90% HR_{max}) to ensure greater pleasurable feelings during the deterioration phase (see Chapter 7 for details). Consequently, based on the above, the use of psychometric tools (i.e. FS, RPE, and EES scale) and HR data could provide an inexpensive and practical exercise intensity-monitoring tool.

This thesis also represents the considerations of individuals' personality characteristics and self-efficacy, to support the adoption of HIIE as a health strategy intervention in the promotion of health benefits. Given marked inter-individual differences that occur mostly in the deterioration phase, several strategies could be adopted by educators or coaches when targeting high BIS and low self-efficacy individuals with HIIE interventions (see Chapter 8 for the details). This includes verbal encouragements or persuasion techniques towards the exerciser during the later stages of HIIE, to boost individuals' self-efficacy and facilitate more enjoyment and positive affect. An attentional dissociation strategy (e.g. diverting attention away from the aversive stimuli by listening to self-selected music) could also be adopted to encourage positive perceptions of feelings (e.g. affect and enjoyment), and perceived ability towards the exercise, particularly during the deterioration phase of HIIE.

9.3 Strengths and limitations of the current research

There are several strengths and limitations that should be acknowledged in this thesis. On strength is that the participants involved in Chapters 6-7 were insufficiently active (90% of participants) and had low cardiorespiratory fitness indicative of elevated cardiometabolic risk (81% of participants), which could augment the generalisability of data for exercise interventions that are substantially required in youth. This is an important consideration given the argument by Biddle and Batterham (2015) that '…it is largely pointless if some forms of PA are shown to produce significant health gains if few people adopt the behaviours''(p.3), especially inactive individuals.

The research embodied in this thesis is limited to exercise conducted in a laboratory, which is unlikely to reflect a participant's real-world perceptual response to exercise. However, the research laboratory was setup in a similar manner each time for participants, and communication with participants was standardised to ensure proper instructions were provided, in addition to creating a sterile environment (e.g. lack of auditory, visual, and social interaction). This was required to ensure accurate comparisons of perceptual (i.e. affect and enjoyment) and cardiorespiratory factors (i.e. HR and $\dot{V}O_2$) across the exercise conditions. Furthermore, access to potentially important information concerning $\dot{V}O_2$, HR and PFC oxygenation data would be difficult in a non-laboratory setting.

Another limitation concerns the reliability to assess all perceptual responses within the work and recovery intervals of exercise conditions in Chapters 5-8. Currently, there is no evidence to suggest the reliability to assess all the scales within a short time frame, but the method used in our study is in line with previous work which has reported multiple items within similar time points during HIIE (Martinez et al., 2015; Niven et al., 2018). Moreover, the nature of the single-item scales itself allows for the collection of data with adequate temporal resolution during the exercise bouts (Van Landuyt et al., 2000). It is also important to note that there is a possibility of erroneous responses (due to confusion or carelessness), due to the single-item measure, as compared to the multi-item measure of the same construct (e.g. PACES). However, to address this issue, participants were given clear instructions and an explanation of the scale before undertaking the exercise protocols (see general methods chapter). Also, all participants were familiarised with using the single-item scales during the incremental test (visit one) before undertaking the exercise conditions for each of the experimental studies.

This thesis focusses on manipulating the work intensities of HIIE work intervals to establish the intensity-affect relationship during HIIE in adolescents. Given that a variety of HIIE protocols have emerged in the paediatric literature, the protocol used in the experimental studies of this thesis should be considered as only one of a multitude of possibilities. Other HIIE protocols (e.g. different work interval durations or different modalities) may generate different perceptual and physiological responses in adolescents. Despite no direct comparisons between HIIE running and cycling, data in this thesis indicates that both modalities generate comparable perceptual and physiological responses. Moreover, the protocol used in this thesis has been considered as a more practical model of HIIE to facilitate multiple health benefits in youth. Although there is no evidence regarding the potential health benefits of each HIIE protocol, HR responses generated during HIIE were evaluated to support the efficiency of this protocol, to promote health benefits in adolescents (Bond et al., 2017) via the HR threshold ≥ 90%HR_{max}. Another potential limitation is that the work in this thesis was limited to adolescents, and it is not possible to extrapolate to children due to potential differences in perceptual responses to exercise (Benjamin et al., 2012).

9.4 Future directions

Given recent recommendations for more research on HIIE in youth for health benefits (e.g. Physical Activity Guidelines Advisory Committee (2018)), the results of the current research provide a foundation for future investigations interested in examining the perceptual responses to HIIE in youth populations. Elucidating affect responses will be equally important from a behavioural point of view. Future research may wish to modify the variables that comprise HIIE (e.g. work-interval duration), to optimise HIIE protocols that could preserve positive affect and enjoyment responses, while maximising physiological adaptation responses to promote health benefits. In turn, this may have the potential to favourably impact exercise adoption and maintenance in youth. Although the DMT does not directly consider the impact of exercise duration on affective responses, a single study by Martinez and colleagues (2015) revealed that short work duration (less than 60 s) compared to longer duration (e.g. 120 s) in overweight adults may not elicit significant disruptions to homeostasis and predicted outcomes of negative affect experienced. Future studies may also seek to expand their sample size to include children and adolescents who present greater challenges for engaging in regular HIIE interventions, such as, minimal experience of VPA, low PA, or overweight and obese.

Another consideration for future research is to examine the perceptual and physiological responses to a self-selected intensity of HIIE. Research has shown that permitting adolescents to self-pace their exercise intensity may result in more positive affective responses compared to prescribed intensity (Stych and Parfitt, 2011, Sheppard and Parfitt, 2008a, Hamlyn-Williams et al., 2014). According to the SDT (Deci and Ryan, 1985), offering the choice to the individual to self-select exercise intensity could encourage the development of intrinsic motivation that plays a role as a central element in promoting exercise adoption and maintenance. Furthermore, research on self-paced HIIE has found that individuals tend to choose self-select intensities that result in greater cardiovascular strain, but these observations were limited to adult men and women (Laurent et al., 2014). Whether a self-paced intensity of HIIE may preserve positive affect responses and maximise the acute cardiorespiratory responses is currently unknown in youth.

Future studies should also explore perceptual responses to repeated exposure of HIIE training, to establish whether an individual may elicit more positive perceptual responses (i.e. improve pleasant and enjoyment feelings and lower the exertional stress). This approach could determine the optimal HIIE training programmes for both long-term physiological adaptations and exercise programme adherence. It is well established that HIIE training interventions ranging from 2-15 weeks promote multiple health benefits (Bond et al., 2017), but the perceptual responses during HIIE training intervention remain unclear. Given that affect responses may be the first link in the exercise adherence chain, this type of investigation is warranted. Furthermore, there are studies available to show that HIIE training elicited improvements in affect and enjoyment responses (i.e. more pleasurable feelings) over two and six weeks in healthy sedentary adults, respectively (Heisz et al., 2016, Saanijoki et al., 2015). Finally, to establish a more complete picture of the association between PFC haemodynamics and affective responses during HIIE, future studies may consider recording multiple areas of the PFC (e.g. the left and right lobe), as differential activation patterns associated with affective responses may occur within multiple areas of the PFC.

9.5 Conclusions

The work contained within this thesis provides a foundation concerning the acute perceptual and physiological responses of HIIE in adolescent boys and girls. Findings show that some permutations of HIIE do not elicit prominent and entirely negative affective responses, as proposed by sceptics (Biddle and Batterham, 2015, Hardcastle et al., 2014), and the DMT, which is based on CHIE and incremental exercise to exhaustion. Importantly, the prescription and implementation of HIIE depends on the type of protocol (e.g. decreasing, increasing, or constant) and work intensity used. This thesis also reveals that changes in affect responses during HIIE can be characterised by preservation and deterioration phases. Each phase indicates the associations among affect with the changes in enjoyment, RPE, PFC oxygenation, and cognitive factors in youth. Hence, this thesis can be used to inform and direct future research in this increasingly important area of affect responses to HIIE, especially given the declining pattern of PA in youth.

REFERENCES

ACEVEDO, E. O., RINEHARDT, K. F. & KRAEMER, R. R. 1994. Perceived exertion and affect at varying intensities of running. *Res Q Exerc Sport,* 65**,** 372-6.

ACEVEDO, E. O., STARKS, M. A. 2011. Exercise testing and prescription lab manual 2nd edition*.* Champaign, IL: Human Kinetics, 29-31.

ADEGBOYE, A. R., ANDERSSEN, S. A., FROBERG, K., SARDINHA, L. B., HEITMANN, B. L., STEENE-JOHANNESSEN, J., KOLLE, E. & ANDERSEN, L. B. 2011. Recommended aerobic fitness level for metabolic health in children and adolescents: a study of diagnostic accuracy. *Br J Sports Med,* 45**,** 722-8.

AJZEN, I. 1991. The theory of planned behavior. *Organ Behav Hum Decis Process,* 50**,** 179-211.

ALLENDER, S., COWBURN, G. & FOSTER, C. 2006. Understanding participation in sport and physical activity among children and adults: a review of qualitative studies. *Health Educ Res,* 21**,** 826-835.

ARIELY, D. & ZAUBERMAN, G. 2003. Differential partitioning of extended experiences. *Organ Behav Hum Decisi Process,* 91**,** 128-139.

ARMSTRONG, N., BALDING, J., GENTLE, P. & KIRBY, B. 1990. Patterns of physical activity among 11 to 16 year old British children. *BMJ,* 301**,** 203-205.

ÅSTRAND, I., ÅSTRAND, P.O., CHRISTENSEN, E. H. & HEDMAN, R. 1960. Intermittent Muscular Work. *Acta Physiologica Scandinavica,* 48**,** 448-453.

BAI, Y., ALLUMS-FEATHERSTON, K., SAINT-MAURICE, P. F., WELK, G. J. & CANDELARIA, N. 2018. Evaluation of Youth Enjoyment Toward Physical Activity and Sedentary Behavior. *Pediatr Exerc Sci,* 30**,** 273-280.

BAILEY, R. C., OLSON, J., PEPPER, S. L., PORSZASZ, J., BARSTOW, T. J. & COOPER, D. M. 1995. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc,* 27**,** 1033-41.

BANDURA, A. 1986. Social foundations of thought and action: A social-cognitive theory. Englewood Cliffs, NJ: Prentice-Hall.

BANDURA, A. 1994. Self-efficacy. *In:* RAMACHAUDRAN, V. S. (ed.) *Encyclopedia of human behavior.* New York: Academic Press: Encyclopedia of mental health.

BANDURA, A. 1997. *Self-efficacy: The exercise of control.,* New York, W. H. Freeman & Co.

BAQUET, G., BERTHOIN, S., GERBEAUX, M. & VAN PRAAGH, E. 2001. High-intensity aerobic training during a 10 week one-hour physical education cycle: effects on physical fitness of adolescents aged 11 to 16. *Int J Sports Med,* 22**,** 295-300.

BARKER, A. R., GRACIA-MARCO, L., RUIZ, J. R., CASTILLO, M. J., APARICIO-UGARRIZA, R., GONZALEZ-GROSS, M., KAFATOS, A., ANDROUTSOS, O., POLITO, A., MOLNAR, D., WIDHALM, K. & MORENO, L. A. 2018. Physical activity, sedentary time, TV viewing, physical fitness and cardiovascular disease risk in adolescents: The HELENA study. *Int J Cardiol,* 254**,** 303-309.

BARKER, A. R., WILLIAMS, C. A., JONES, A. M. & ARMSTRONG, N. 2011. Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. *Br J Sports Med,* 45**,** 498-503.

BARKLEY, J. E., EPSTEIN, L. H. & ROEMMICH, J. N. 2009. Reinforcing Value of Interval and Continuous Physical Activity In Children. *Physiol Behav,* 98**,** 31-36.

BARON, L. J. & DOWNEY, P. J. 2007. Perceived success and enjoyment in elementary physical education *J Appl Res Learning,* 1**,** 1-24.

BECKER, M. H. 1974. The Health Belief Model and personal health behavior. *Health Educ Monogr,* 2**,** 324-508.

BENJAMIN, C. C., ROWLANDS, A. & PARFITT, G. 2012. Patterning of affective responses during a graded exercise test in children and adolescents. *Pediatr Exerc Sci,* 24**,** 275-88.

BERGER, B. G. & MOTL, R. W. 2000. Exercise and mood: A selective review and synthesis of research employing the profile of mood states. *J App Sport Psychol,* 12**,** 69-92.

BHAMBHANI, Y., MALIK, R. & MOOKERJEE, S. 2007. Cerebral oxygenation declines at exercise intensities above the respiratory compensation threshold. *Respir Physiol Neurobiol,* 156**,** 196-202.

BIDDLE, S. J. & BATTERHAM, A. M. 2015. High-intensity interval exercise training for public health: a big HIT or shall we HIT it on the head? *Int J Behav Nutr Phys Act,* 12**,** 95.

BILLAT, L. V. 2001. Interval training for performance: a scientific and empirical practice: special recommendations for middle- and long-distance running: part I: aerobic interval training. *Sports Med,* 31**,** 13-31.

BIXBY, W. R., SPALDING, T. W. & HATFIELD, B. D. 2001. Temporal dynamics and dimensional specificity of the affective response to exercise of varying intensity: Differing pathways to a common outcome. *J Sport Exerc Psychol,* 23**,** 171-190.

BLANCHARD, C. M., RODGERS, W. M., WILSON, P. M. & BELL, G. J. 2004. Does Equating Total Volume of Work between Two Different Exercise Conditions Matter When Examining Exercise-Induced Feeling States? *Res Q Exerc Sport,* 75**,** 209-215.

BOND, B., GATES, P. E., JACKMAN, S. R., CORLESS, L. M., WILLIAMS, C. A. & BARKER, A. R. 2015a. Exercise intensity and the protection from postprandial vascular dysfunction in adolescents. *Am J Physiol Heart Circ Physiol,* 308 (11)**,** H1443-H1450.

BOND, B., HIND, S., WILLIAMS, C. A. & BARKER, A. R. 2015b. The Acute Effect of Exercise Intensity on Vascular Function in Adolescents. *Med Sci Sports Exerc,* 47**,** 2628-2635.

BOND, B., WILLIAMS, C. A., ISIC, C., JACKMAN, S. R., TOLFREY, K., BARRETT, L. A. & BARKER, A. R. 2015c. Exercise intensity and postprandial health outcomes in adolescents. *Eur J Appl Physiol,* 115**,** 927-936.

BOND, B., WESTON, K. L., WILLIAMS, C. A. & BARKER, A. R. 2017. Perspectives on high-intensity interval exercise for health promotion in children and adolescents. *Open Access J Sports Med,* 8.

Borg, G. (1962). Physical performance and perceived exertion. Lund: Gleerup.

BORDE, R., SMITH, J. J., SUTHERLAND, R., NATHAN, N. & LUBANS, D. R. 2017. Methodological considerations and impact of school-based interventions on objectively measured physical activity in adolescents: a systematic review and meta-analysis. *Obes Rev,* 18**,** 476-490.

BOYD, J. C., SIMPSON, C. A., JUNG, M. E. & GURD, B. J. 2013. Reducing the intensity and volume of interval training diminishes cardiovascular adaptation but not mitochondrial biogenesis in overweight/obese men. *PLoS One,* 8**,** e68091.

BUCHHEIT, M. & LAURSEN, P. B. 2013. High-intensity interval training, solutions to the programming puzzle: Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Med,* 43**,** 927-54.

BUTT, J., WEINBERG, R. S., BRECKON, J. D. & CLAYTOR, R. P. 2011. Adolescent physical activity participation and motivational determinants across gender, age, and race. *J Phys Act Health,* 8**,** 1074-1083.

CABANAC, M. 1971. Physiological role of pleasure. *Sci,* 173**,** 1103-7.

CARSON, V., RINALDI, R. L., TORRANCE, B., MAXIMOVA, K., BALL, G. D., MAJUMDAR, S. R., PLOTNIKOFF, R. C., VEUGELERS, P., BOULE, N. G., WOZNY, P., MCCARGAR, L., DOWNS, S., DAYMONT, C., LEWANCZUK, R. & MCGAVOCK, J. 2014. Vigorous physical activity and longitudinal associations with cardiometabolic risk factors in youth. *Int J Obes (Lond),* 38**,** 16-21.

CARVER, C. S. & WHITE, T. L. 1994. Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *J Pers Soc Psychol,* 67**,** 319-333.

CASPERSEN, C. J., POWELL, K. E. & CHRISTENSON, G. M. 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports,* 100**,** 126-131.

CHRISTENSEN, E. H., HEDMAN, R. & SALTIN, B. 1960. Intermittent and Continuous Running (A further contribution to the physiology of intermittent work.). *Acta Physiologica Scandinavica,* 50**,** 269-286.

COCKCROFT, E. J., WILLIAMS, C. A., TOMLINSON, O. W., VLACHOPOULOS, D., JACKMAN, S. R., ARMSTRONG, N. & BARKER, A. R. 2015. High intensity interval exercise is an effective alternative to moderate intensity exercise for improving glucose tolerance and insulin sensitivity in adolescent boys. *J Sci Med Sport,* 18**,** 720-4.

COHEN, J. 1988. Statistical power analysis for the behavioural sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; pp 22-5.

COLE, T. J., BELLIZZI, M. C., FLEGAL, K. M. & DIETZ, W. H. 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ,* 320**,** 1240-3.

COOPER, A., GOMEZ, R. & AUCOTE, H. 2007. The Behavioral Inhibition System and Behavioral Approach System (BIS/BAS) Scales: Measurement and structural invariance across adults and adolescents. *Pers Indiv Diff,* 43**,** 295-305.

COQUART, J. B. J., DUFOUR, Y., GROSLAMBERT, A., MATRAN, R. & GARCIN, M. 2012. Relationships between psychological factors, RPE and time limit estimated by teleoanticipation. *Sport Psychol,* 26**,** 359-374.

COSTIGAN, S. A., EATHER, N., PLOTNIKOFF, R. C., TAAFFE, D. R. & LUBANS, D. R. 2015. High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. *Br J Sports Med,* 49**,** 1253-1261.

COYLE, E. F. 2005. Very intense exercise-training is extremely potent and time efficient: a reminder. *J Appl Physiol (1985),* 98**,** 1983-4.

CRAIG, S., GOLDBERG, J. & DIETZ, W. H. 1996. Psychosocial correlates of physical activity among fifth and eighth graders. *Prev Med,* 25**,** 506-13.

CRISP, N. A., FOURNIER, P. A., LICARI, M. K., BRAHAM, R. & GUELFI, K. J. 2012. Adding sprints to continuous exercise at the intensity that maximises fat oxidation: implications for acute energy balance and enjoyment. *Metabolism,* 61**,** 1280-8.

DALEY, A. J. & MAYNARD, I. 2003. Affect and choice of exercise mode during and after acute exercise. *J Sport Sci,* 21**,** 267-268.

DE BOURDEAUDHUIJ, I., LEFEVRE, J., DEFORCHE, B., WIJNDAELE, K., MATTON, L. & PHILIPPAERTS, R. 2005. Physical activity and psychosocial correlates in normal weight and overweight 11 to 19 year olds. *Obes Res,* 13**,** 1097-105.

DECI, E. & RYAN, R. 1985. Intrinsic motivation and self-determination in human behavior. Plenum, New York.

DECKER, E. S. & EKKEKAKIS, P. 2016. More efficient, perhaps, but at what price? Pleasure and enjoyment responses to high-intensity interval exercise in low-active women with obesity. *Psychol Sport Exerc,* 28**,** 1-10.

DEPARTMENT OF HEALTH, P. A., HEALTH IMPROVEMENT AND PROTECTION 2011. Start active, stay active: a report on physical activity from the four home countries. Chief Medical Officers: Crown Publishers London.

DIETRICH, A. 2006. Transient hypofrontality as a mechanism for the psychological effects of exercise. *Psychiatry Res,* 145**,** 79-83.

DILORENZO, T. M., STUCKY-ROPP, R. C., VANDER WAL, J. S. & GOTHAM, H. J. 1998. Determinants of exercise among children. II. A longitudinal analysis. *Prev Med,* 27**,** 470-7.

DISHMAN, R., MOTL, R., SAUNDERS, R., FELTON, G., WARD, D., DOWDA, M. & PATE, R. 2005. Enjoyment mediates effects of a school-based physical-activity intervention. *Med Sci Sports Exerc,* 37**,** 478 - 87.

DUNCAN, A., MEEK, J. H., CLEMENCE, M., ELWELL, C. E., FALLON, P., TYSZCZUK, L., COPE, M. & DELPY, D. T. 1996. Measurement of Cranial Optical Path Length as a Function of Age Using Phase Resolved Near Infrared Spectroscopy. *Pediatr Res,* 39**,** 889-894.

EKKEKAKIS, P. 2003. Pleasure and displeasure from the body : Perspective from exercise. *Cog Emot,* 17**,** 213-239.

EKKEKAKIS, P. 2009. Illuminating the black box: investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. *J Sport Exerc Psychol,* 31**,** 505-53.

EKKEKAKIS, P. & ACEVEDO, E. O. 2006. Affective responses to acute exercise: Toward a psychobiological dose-response model. *In:* Acevedo, E. O. & Ekkekakis, P. (Eds.) *Psychobiology of physical activity.* Champaign, IL: Human Kinetics.

EKKEKAKIS, P., HALL, E. E. & PETRUZZELLO, S. J. 2005a. Some Like It Vigorous: Measuring Individual Differences in the Preference for and Tolerance of Exercise Intensity. *J Sport Exerc Psychol,* 27**,** 350-374.

EKKEKAKIS, P., HALL, E. E. & PETRUZZELLO, S. J. 2005b. Variation and homogeneity in affective responses to physical activity of varying intensities: an alternative perspective on dose-response based on evolutionary considerations. *J Sports Sci,* 23**,** 477-500.

EKKEKAKIS, P., PARFITT, G. & PETRUZZELLO, S. J. 2011. The pleasure and displeasure people feel when they exercise at different intensities: decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Med,* 41**,** 641-71.

EKKEKAKIS, P. & PETRUZZELLO, S. J. 1999. Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. *Sports Med,* 28**,** 337-74.

EKKEKAKIS, P. & PETRUZZELLO, S. J. 2000. Analysis of the affect measurement conundrum in exercise psychology: I. Fundamental issues. *Psychol Sport and Exerc,* 1**,** 71-88.

EKKEKAKIS, P. & PETRUZZELLO, S. J. 2002. Analysis of the affect measurement conundrum in exercise psychology: IV. A conceptual case for the affect circumplex. *Psychol Sport Exerc,* 3**,** 35-63.

EPSTEIN, L. H. & ROEMMICH, J. N. 2001. Reducing sedentary behavior: role in modifying physical activity. *Exerc Sport Sci Rev,* 29**,** 103-8.

FAUL, F., ERDFELDER, E., LANG, A.-G. & BUCHNER, A. 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods,* 39**,** 175-191.

FAWKNER, S. G., ARMSTRONG, N., CHILDS, D. J. & WELSMAN, J. R. 2002. Reliability of the Visually Identified Ventilatory Threshold and V-Slope in Children. *Pediatr Exerc Sci,* 14**,** 181-192.

FOCHT, B. C. 2013. Affective responses to 10-minute and 30-minute walks in sedentary, overweight women: Relationships with theory-based correlates of walking for exercise. *Psychol Sport Exerc,* 14**,** 759-766.

FOX, K. 1991. Motivating children for physical activity: towards a health future. *J Phys Educ Health Recreat Dance,* 62**,** 290-302.

FRAZAO, D. T., DE FARIAS JUNIOR, L. F., DANTAS, T. C., KRINSKI, K., ELSANGEDY, H. M., PRESTES, J., HARDCASTLE, S. J. & COSTA, E. C. 2016. Feeling of Pleasure to High-Intensity Interval Exercise Is Dependent of the Number of Work Bouts and Physical Activity Status. *PLoS One,* 11**,** e0152752.

FREDRICKSON, B. L. 2000. Extracting meaning from past affective experiences: The importance of peaks, ends, and specific emotions. *Cogn and Emot,* 14**,** 577-606.

FREDRICKSON, B. L. & KAHNEMAN, D. 1993. Duration neglect in retrospective evaluations of affective episodes. *J Pers Soc Psychol,* 65**,** 45-55.

GAESSER, G. A. & POOLE, D. C. 1996. The slow component of oxygen uptake kinetics in humans. *Exerc Sport Sci Rev,* 24**,** 35-71.

GANESAN, G., LEU, S.-Y., CERUSSI, A., TROMBERG, B., COOPER, D. M. & GALASSETTI, P. 2016. Cerebral and Muscle Tissue Oxygenation During Incremental Cycling in Male Adolescents Measured by Time-Resolved NIRS. *Pediatr Exerc Sci,* 28**,** 275-285.

GAUVIN, L. & REJESKI, W. J. 1993. The Exercise-Induced Feeling Inventory: Development and Initial Validation. *J Sport Exerc Psychol,* 15**,** 403-423.

GIBALA, M. J., LITTLE, J. P., MACDONALD, M. J. & HAWLEY, J. A. 2012. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol,* 590**,** 1077-84.

GIBALA, M. J., LITTLE, J. P., VAN ESSEN, M., WILKIN, G. P., BURGOMASTER, K. A., SAFDAR, A., RAHA, S. & TARNOPOLSKY, M. A. 2006. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol,* 575**,** 901-11.

GRAY, J. A. Neural systems, emotion, and personality (1991). In: Neurobiology of Learning, Emotion, and Affect, J. Madden (Ed.). New York: Raven Press, pp. 273–306.

GRAY, J. A. 1993. Framework for a taxonomy of psychiatric disorder. *In:* IN S. VAN GOZEN, N. V. D. P., & J. A. SERGEANT (Eds.). *Emotions: Essays on emotion theory (pp.29-59).* New Jersey: Lawrence Erlbaum Associates Inc.

GROSLAMBERT, A. & MAHON, A. D. 2006. Perceived exertion : influence of age and cognitive development. *Sports Med,* 36**,** 911-28.

HALL, E. E., EKKEKAKIS, P. & PETRUZZELLO, S. J. 2002. The affective beneficence of vigorous exercise revisited. *Br J Health Psychol,* 7**,** 47-66.

HALL, E. E., EKKEKAKIS, P. & PETRUZZELLO, S. J. 2005. Is the Relationship of RPE to Psychological Factors Intensity-Dependent? *Med Sci Sports Exerc,* 37**,** 1365-1373.

HAMLYN-WILLIAMS, C. C., FREEMAN, P. & PARFITT, G. 2014. Acute affective responses to prescribed and self-selected exercise sessions in adolescent girls: an observational study. *BMC Sports Sci Med Rehabil,* 6**,** 35.

HARDCASTLE, S. J., RAY, H., BEALE, L. & HAGGER, M. S. 2014. Why sprint interval training is inappropriate for a largely sedentary population. *Front Psychol,* 5**,** 1505.

HARDY, C. J. & REJESKI, W. J. 1989. Not What, But How One Feels: The Measurement of Affect During Exercise. *J Sport Exer Psychol,* 11**,** 304–317.

HARGREAVES, E. A. & STYCH, K. 2013. Exploring the peak and end rule of past affective episodes within the exercise context. *Psychol Sport Exerc,* 14**,** 169-178.

HAVERLY, K. & DAVISON, K. K. 2005. Personal fulfillment motivates adolescents to be physically active. *Arch Pediatr Adolesc Med,* 159**,** 1115-20.

HAY, J., MAXIMOVA, K., DURKSEN, A., CARSON, V., RINALDI, R. L., TORRANCE, B., BALL, G. D., MAJUMDAR, S. R., PLOTNIKOFF, R. C., VEUGELERS, P., BOULE, N. G., WOZNY, P., MCCARGAR, L., DOWNS, S., LEWANCZUK, R. & MCGAVOCK, J. 2012. Physical activity intensity and cardiometabolic risk in youth. *Arch Pediatr Adolesc Med,* 166**,** 1022-9.

HEISZ, J. J., TEJADA, M. G. M., PAOLUCCI, E. M. & MUIR, C. 2016. Enjoyment for High-Intensity Interval Exercise Increases during the First Six Weeks of Training: Implications for Promoting Exercise Adherence in Sedentary Adults. *PLoS One,* 11**,** e0168534.

HOFFMAN, S. J. & KNUDSON, D. V. 2018. Introduction to Kinesiology. *In:* HOFFMAN, S. J. & KNUDSON, D. V. (Eds.) The importance of physical activity experiences: *Subjective experience of physical activity.* Fifth ed. Champaign, IL: Human Kinetics.

HUOTARI, P., NUPPONEN, H., MIKKELSSON, L., LAAKSO, L. & KUJALA, U. 2011. Adolescent physical fitness and activity as predictors of adulthood activity. *J Sports Sci,* 29**,** 1135-41.

INGUL, C. B., TJONNA, A. E., STOLEN, T. O., STOYLEN, A. & WISLOFF, U. 2010. Impaired cardiac function among obese adolescents: effect of aerobic interval training. *Arch Pediatr Adolesc Med,* 164**,** 852-9.

JANSSEN, I. & LEBLANC, A. G. 2010. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act,* 7**,** 40.

JIMENEZ-PAVON, D. & LAVIE, C. J. 2017. High-intensity intermittent training versus moderate-intensity intermittent training: is it a matter of intensity or intermittent efforts? *Br J Sports Med,* 51**,** 1319-1320.

JONES, A. M. & DOUST, J. H. 1996. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *J Sports Sci,* 14**,** 321-7.

JUNG, M. E., BOURNE, J. E. & LITTLE, J. P. 2014. Where does HIT fit? An examination of the affective response to high-intensity intervals in comparison to continuous moderate- and continuous vigorous-intensity exercise in the exercise intensity-affect continuum. *PLoS One,* 9**,** e114541.

KAHNEMAN, D. 2003. Objectives happiness. *In:* KAHENMAN, D., DIENER, E. & SCHWARZ, N. (Eds.) *Well-being: the foundation of hedonic psychology.* New york (NY): Russell Sage Foundation.

KAHNEMAN, D., FREDRICKSON, B. L., SCHREIBER, C. A. & REDELMEIER, D. A. 1993. When More Pain Is Preferred to Less: Adding a Better End. *Psychol Sci,* 4**,** 401-405.

KILPATRICK, M. W., BORTZFIELD, A. L. & GIBLIN, L. M. 2012. Impact of aerobic exercise trials with varied intensity patterns on perceptions of effort: an evaluation of predicted, in-task, and session exertion. *J Sports Sci,* 30**,** 825-32.

KILPATRICK, M., KRAEMER, R., BARTHOLOMEW, J., ACEVEDO, E. & JARREAU, D. 2007. Affective responses to exercise are dependent on intensity rather than total work. *Med Sci Sports Exerc,* 39**,** 1417-22.

KILPATRICK, M. W., GREELEY, S. J. & COLLINS, L. H. 2015a. The Impact of Continuous and Interval Cycle Exercise on Affect and Enjoyment. *Res Q Exerc Sport,* 86**,** 244-51.

KILPATRICK, M. W., MARTINEZ, N., LITTLE, J. P., JUNG, M. E., JONES, A. M., PRICE, N. W. & LENDE, D. H. 2015b. Impact of high-intensity interval duration on perceived exertion. *Med Sci Sports Exerc,* 47**,** 1038-45.

KIMIECIK, J. C., HARRIS, A. T. & 1996. What Is Enjoyment? A Conceptua/Definitional Analysis With Implications for Sport and Exercise Psychology. *J Sport Exerc Psychol,* 18**,** 247-263.

KIRKCALDY, B. C. & SHEPHARD, R. J. 1990. Therapeutic implications of exercise. *Int J Sport Psychol,* 21**,** 165-184.

KIVINIEMI, M. T., VOSS-HUMKE, A. M. & SEIFERT, A. L. 2007. How do I feel about the behavior? The interplay of affective associations with behaviors and cognitive beliefs as influences on physical activity behavior. *Health Psychol,* 26**,** 152-8.

KWAN, B. M. & BRYAN, A. D. 2010. Affective response to exercise as a component of exercise motivation: Attitudes, norms, self-efficacy, and temporal stability of intentions. *Psychol Sport Exerc,* 11**,** 71-79.

LANG, P. J. 1980. Behavioral treatment and bio-behavioral assessment: computer applications. *In:* IN J. B. SIDOWSKI, J. H. J., & T. A. WILLIAMS (Eds.). *Technology in mental health care delivery systems.* Norwood, NJ: Ablex.

LAURENT, C. M., VERVAECKE, L. S., KUTZ, M. R. & GREEN, J. M. 2014. Sex-specific responses to self-paced, high-intensity interval training with variable recovery periods. *J Strength Cond Res,* 28**,** 920-7.

LAZARUS, R. S. 1991. *Emotion and Adaptation,* New York, Oxford University Press.

LEVENTHAL, H. & EVERHART, D. 1979. Emotion, Pain, and Physical Illness. *In:* IZARD, C. E. (ed.) *Emotions in Personality and Psychopathology.* Boston, MA: Springer US.

LITTLE, J. P., GILLEN, J. B., PERCIVAL, M. E., SAFDAR, A., TARNOPOLSKY, M. A., PUNTHAKEE, Z., JUNG, M. E. & GIBALA, M. J. 2011. Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. *J Appl Physiol* 111**,** 1554-60.

LOGAN, G. M., HARRIS, N., DUNCAN, S. & SCHOFIELD, G. 2014. A Review of Adolescent High-Intensity Interval Training. *Sports Med,* 44**,** 1071-1085.

LUSZCZYK, M., KUJACH, S., OLEK, R. A., LASKOWSKI, R. & SZCZESNA-KACZMAREK, A. Prefrontal Cortex Oxygenation and Muscle Oxygenation during Incremental Exercise in Children: A near-infrared spectroscopy study. *In:* WILLIAMS, C. A. & ARMSTRONG, N., eds. Children and Exercise XXVII (Proceedings of the XXVII International Symposium of the European Group of Pediatric Work Physiology), 2011 Exeter, United Kingdom. 83-89.

MALIK, A. A., WILLIAMS, C. A., BOND, B., WESTON, K. L. & BARKER, A. R. 2017. Acute cardiorespiratory, perceptual and enjoyment responses to high-intensity interval exercise in adolescents. *Eur J Sport Sci,* 17**,** 1335-1342.

MALIK, A. A., WILLIAMS, C. A., WESTON, K. L. & BARKER, A. R. 2018a. Perceptual and prefrontal cortex haemodynamic responses to high-intensity interval exercise with decreasing and increasing work-intensity in adolescents. *Int J Psychophysiol*, S0167-8760, 30223-X.

MALIK, A. A., WILLIAMS, C. A., WESTON, K. L. & BARKER, A. R. 2018b. Perceptual Responses to High- and Moderate-Intensity Interval Exercise in Adolescents. *Med Sci Sports Exerc,* 50**,** 1021-1030.

MARTENS, R. 1996. Turning kids on to physical activity for a lifetime. *Quest,* 48**,** 303-310.

MARTINEZ, N., KILPATRICK, M. W., SALOMON, K., JUNG, M. E. & LITTLE, J. P. 2015. Affective and Enjoyment Responses to High-Intensity Interval Training in Overweight-to-Obese and Insufficiently Active Adults. *J Sport Exerc Psychol,* 37**,** 138-49.

MCAULEY, E. & COURNEYA, K. S. 1992. Self-Efficacy Relationships With Affective and Exertion Responses to Exercise1. *J App Soc Psychol,* 22**,** 312-326.

MCCRAE, C. P. J. (2000). Nature over nurture: temperament, personality, and life span development. *J Pers Soc Psychol*, *78*(1), 173–86.

MCNAIR, D. M., LORR, M. & DROPPLEMAN, L. F. 1971. Profile of Mood States (POMS) Manual. San Diego: CA: Education and Industrial Testing Service.

MCAULEY, E. & COURNEYA, K. S. 1994. The Subjective Exercise Experiences Scale (SEES): Development and Preliminary Validation. *J Sport Exerc Psychol,* 16**,** 163-177.

METCALF, B., HENLEY, W. & WILKIN, T. 2012. Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes (EarlyBird 54). *BMJ,* 345.

MILLET, G. P., VLECK, V. E. & BENTLEY, D. J. 2009. Physiological differences between cycling and running: lessons from triathletes. *Sports Med,* 39**,** 179-206.

MOORE, S. A., MCKAY, H. A., MACDONALD, H., NETTLEFOLD, L., BAXTER-JONES, A. D., CAMERON, N. & BRASHER, P. M. 2015. Enhancing a Somatic Maturity Prediction Model. *Med Sci Sports Exerc,* 47**,** 1755-64.

MORRIS, N. M. & UDRY, J. R. 1980. Validation of a self-administered instrument to assess stage of adolescent development. *J Youth Adolesc,* 9**,** 271-80.

MOTL, R. W., DISHMAN, R. K., SAUNDERS, R., DOWDA, M., FELTON, G. & PATE, R. R. 2001. Measuring enjoyment of physical activity in adolescent girls. *Am J Prev Med,* 21**,** 110-7.

MURIS, P., MEESTERS, C., DE KANTER, E. & TIMMERMAN, P. E. 2005. Behavioural inhibition and behavioural activation system scales for children: relationships with Eysenck's personality traits and psychopathological symptoms. *Personality and Individual Differences,* 38**,** 831-841.

NAGY, E., VICENTE-RODRIGUEZ, G., MANIOS, Y., BEGHIN, L., ILIESCU, C., CENSI, L., DIETRICH, S., ORTEGA, F. B., DE VRIENDT, T., PLADA, M., MORENO, L. A. & MOLNAR, D. 2008. Harmonization process and reliability assessment of anthropometric measurements in a multicenter study in adolescents. *Int J Obes (Lond),* 32 Suppl 5**,** S58-65.

NASUTI, G. & RHODES, R. E. 2013. Affective Judgment and Physical Activity in Youth: Review and Meta-Analyses. *Ann Behav Med,* 45**,** 357-376.

NIVEN, A., THOW, J., HOLROYD, J., TURNER, A. P. & PHILLIPS, S. M. 2018. 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. *J Sports Sci*, 1-9.

NOBLE, B. J. & ROBERTSON, R. J. 1996. *Perceived exertion,* Champaign (IL), Human Kinetics,.

OJANEN, M. 1994. Can the true effects of exercise on psychological variables be separated from placebo effects?. *Int. J. Sport Psychol,* 25, 63-80.

OLIVEIRA, B. R., SLAMA, F. A., DESLANDES, A. C., FURTADO, E. S. & SANTOS, T. M. 2013. Continuous and high-intensity interval training: which promotes higher pleasure? *PLoS One,* 8, e79965.

OLIVEIRA, B. R., VIANA, B. F., PIRES, F., OLIVEIRA, M. J. & SANTOS, T. M. 2015. Prediction of Affective Responses in Aerobic Exercise Sessions. *CNS Neurol Disord Drug Targets,* 14, 1214-1218.

OWEN, K. B., SMITH, J., LUBANS, D. R., NG, J. Y. & LONSDALE, C. 2014. Self-determined motivation and physical activity in children and adolescents: a systematic review and meta-analysis. *Prev Med,* 67, 270-9.

PAGEAUX, B. 2016. Perception of effort in Exercise Science: Definition, measurement and perspectives. *Eur J Sport Sci,* 16, 885-94.

PANISSA, V. L., JULIO, U. F., FRANCA, V., LIRA, F. S., HOFMANN, P., TAKITO, M. Y. & FRANCHINI, E. 2016. Sex-Related Differences in Self-Paced All Out High-Intensity Intermittent Cycling: Mechanical and Physiological Responses. *J Sports Sci Med,* 15, 372-8.

PANISSA, V. L., JULIO, U. F., PINTO, E. S. C. M., ANDREATO, L. V., SCHWARTZ, J. & FRANCHINI, E. 2014. Influence of the aerobic fitness on time spent at high percentage of maximal oxygen uptake during a high-intensity intermittent running. *J Sports Med Phys Fitness,* 54**,** 708-14.

PARFITT, G., ALRUMH, A. & ROWLANDS, A. V. 2012. Affect-regulated exercise intensity: does training at an intensity that feels 'good' improve physical health? *J Sci Med Sport,* 15**,** 548-53.

PARFITT & ESTON, R. 1995. Changes in ratings of perceived exertion and psychological affect in the early stages of exercise. *Percept Mot Skills,* 80**,** 259-66.

PARFITT, G. & HUGHES, S. 2009. The Exercise Intensity–Affect Relationship: Evidence and Implications for Exercise Behavior. *J Exerc Sci Fit,* 7**,** S34-S41.

PARFITT, G., ROSE, E. A. & BURGESS, W. M. 2006. The psychological and physiological responses of sedentary individuals to prescribed and preferred intensity exercise. *Br J Health Psychol,* 11**,** 39-53.

PENDER, N. J., BAR-OR, O., WILK, B. & MITCHELL, S. 2002. Self-efficacy and perceived exertion of girls during exercise. *Nursing Research,* 51**,** 86-91.

PHILLIPS, L., PARFITT, G. & ROWLANDS, A. 2013. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport,* 16**,** 124-128.

PLOTNIKOFF, R. C., COSTIGAN, S. A., KARUNAMUNI, N. & LUBANS, D. R. 2013. Social cognitive theories used to explain physical activity behavior in adolescents: a systematic review and meta-analysis. *Prev Med,* 56**,** 245-53.

POOLE, D. C., BARSTOW, T. J., GAESSER, G. A., WILLIS, W. T. & WHIPP, B. J. 1994. VO2 slow component: physiological and functional significance. *Med Sci Sports Exerc,* 26**,** 1354-8.

PROCHASKA, J. O. & VELICER, W. F. 1997. The transtheoretical model of health behavior change. *Am J Health Promot,* 12**,** 38-48.

PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE. 2018. *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, DC: U.S. Department of Health and Human Services.

RAEDEKE, T. D. 2007. The relationship between enjoyment and affective responses to exercise. *J Appl Sport Psychol,* 19**,** 105-115.

REED, J. & ONES, D. S. 2006. The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychol Sport Exerc,* 7**,** 477-514.

REJESKI, W. J. 1985. Perceived exertion: An active or passive process? *J Sport Psychol,* 7**,** 371-378.

RHODES, R. E. & KATES, A. 2015. Can the Affective Response to Exercise Predict Future Motives and Physical Activity Behavior? A Systematic Review of Published Evidence. *Ann Behav Med,* 49**,** 715-31.

RHODES, R. E. & SMITH, N. E. I. 2006. Personality correlates of physical activity: a review and meta-analysis. *Br J Sports Med,* 40**,** 958-965.

RIDDOCH, C. J., MATTOCKS, C., DEERE, K., SAUNDERS, J., KIRKBY, J., TILLING, K., LEARY, S. D., BLAIR, S. N. & NESS, A. R. 2007. Objective measurement of levels and patterns of physical activity. *Arch Dis Child,* 92**,** 963-9.

ROBBINS, L. B., PENDER, N. J., RONIS, D. L., KAZANIS, A. S. & PIS, M. B. 2004. Physical activity, self-efficacy, and perceived exertion among adolescents. *Res Nurs Health,* 27**,** 435-46.

ROBERTSON, R. J., GOSS, F. L., BOER, N. F., PEOPLES, J. A., FOREMAN, A. J., DABAYEBEH, I. M., MILLICH, N. B., BALASEKARAN, G., RIECHMAN, S. E.,

GALLAGHER, J. D. & THOMPKINS, T. 2000. Children's OMNI scale of perceived exertion: mixed gender and race validation. *Med Sci Sports Exerc,* 32**,** 452-8.

ROBERTSON, R. J. & NOBLE, B. J. 1997. Perception of physical exertion: methods, mediators, and applications. *Exerc Sport Sci Rev,* 25**,** 407-52.

ROOKS, C. R., THOM, N. J., MCCULLY, K. K. & DISHMAN, R. K. 2010. Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: a systematic review. *Prog Neurobiol,* 92**,** 134-50.

ROSE, E. A. & PARFITT, G. 2007. A quantitative analysis and qualitative explanation of the individual differences in affective responses to prescribed and self-selected exercise intensities. *J Sport Exerc Psychol,* 29**,** 281-309.

ROSE, E. A. & PARFITT, G. 2010. Pleasant for some and unpleasant for others: a protocol analysis of the cognitive factors that influence affective responses to exercise. *Int J Behav Nutr Phys Act,* 7**,** 15.

ROSE, E. A. & PARFITT, G. 2012. Exercise experience influences affective and motivational outcomes of prescribed and self-selected intensity exercise. *Scand J Med Sci Sports,* 22**,** 265-77.

RUIZ, J. R., RIZZO, N. S., HURTIG-WENNLOF, A., ORTEGA, F. B., WARNBERG, J. & SJOSTROM, M. 2006. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. *Am J Clin Nutr,* 84**,** 299-303.

RUSSELL, J. A. 1980. A Circumplex Model of Affect. *J Pers Soc Psychol,* 39**,** 1161-1178.

RUSSELL, J. A. 2003. Core affect and the psychological construction of emotion. *Psychol Rev,* 110**,** 145-72.

RUSSELL, J. A. 2009. Emotion, core affect, and psychological construction. *Cognition and Emotion,* 23**,** 1259-1283.

RUSSELL, J. A. & FELDMAN BARRETT, L. 1999. Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *J Pers Soc Psychol,* 76**,** 805-819.

RUSSELL, J. A., WEISS, A. & MENDELSOHN, G. A. 1989. Affect Grid: A single-item scale of pleasure and arousal. *J Pers Soc Psychol,* 57**,** 493–502.

SAANIJOKI, T., NUMMENMAA, L., ESKELINEN, J. J., SAVOLAINEN, A. M., VAHLBERG, T., KALLIOKOSKI, K. K. & HANNUKAINEN, J. C. 2015. Affective Responses to Repeated Sessions of High-Intensity Interval Training. *Med Sci Sports Exerc,* 47**,** 2604-11.

SALLIS, J. F., PROCHASKA, J. J. & TAYLOR, W. C. 2000. A review of correlates of physical activity of children and adolescents. *Med Sci Sports Exerc,* 32**,** 963-75.

SALMON, J., BROWN, H. & HUME, C. 2009. Effects of strategies to promote children's physical activity on potential mediators. *Int J Obes,* 33**,** S66-S73.

SCHNEIDER, M. & COOPER, D. M. 2011. Enjoyment of exercise moderates the impact of a school-based physical activity intervention. *Int J Behav Nutr Phys Act,* 8**,** 64.

SCHNEIDER, M., DUNN, A. & COOPER, D. 2009a. Affect, exercise, and physical activity among healthy adolescents. *J Sport Exerc Psychol,* 31**,** 706-23.

SCHNEIDER, M. L. & GRAHAM, D. J. 2009b. Personality, physical fitness, and affective response to exercise among adolescents. *Med Sci Sports Exerc,* 41**,** 947-55.

SEDGWICK, M. J., MORRIS, J. G., NEVILL, M. E. & BARRETT, L. A. 2015. Effect of repeated sprints on postprandial endothelial function and triacylglycerol concentrations in adolescent boys. *J Sports Sci,* 33**,** 806-16.

SHEPPARD, K. E. & PARFITT, G. 2008a. Acute affective responses to prescribed and self-selected exercise intensities in young adolescent boys and girls. *Pediatr Exerc Sci,* 20**,** 129-41.

SHEPPARD, K. E. & PARFITT, G. 2008b. Patterning of physiological and affective responses during a graded exercise test in sedentary men and boys. *J Exerc Sci Fit,* 6**,** 121-129.

SILVA, D. R., RIBEIRO, A. S., PAVAO, F. H., RONQUE, E. R., AVELAR, A., SILVA, A. M. & CYRINO, E. S. 2013. Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: a systematic review. *Rev Assoc Med Bras (1992),* 59**,** 475-86.

SLAUGHTER, M. H., LOHMAN, T. G., BOILEAU, R. A., HORSWILL, C. A., STILLMAN, R. J., VAN LOAN, M. D. & BEMBEN, D. A. 1988. Skinfold equations for estimation of body fatness in children and youth. *Hum Biol,* 60**,** 709-23.

SOLOMON, R. L. 1991. Acquired motivation and affective opponent-processes. *In:* MADDEN, I. I. V. J. (Ed.) *Neurobiology of learning, emotion, and affect.* New York, NY: Raven.

SPIELBERGER, C. D., GORSUCH, R. L., & LUSHENE, R. E. (1970). Manual for the State-Trait Anxiety Inventory. Palo Alto, CA: Consulting Psychologists Press.

STANLEY, D. M. & CUMMING, J. 2010. Are we having fun yet? Testing the effects of imagery use on the affective and enjoyment responses to acute moderate exercise. *Psychol Sport Exerc,* 11**,** 582-590.

STANLEY, D. M., WILLIAMS, S. E. & CUMMING, J. 2009. Preliminary validation of a single-item measure of exercise enjoyment: The Exercise Enjoyment Scale. *J Sport Exerc Psychol,* 31**,** S138–S139.

STEELE, R. M., VAN SLUIJS, E. M., CASSIDY, A., GRIFFIN, S. J. & EKELUND, U. 2009. Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. *Am J Clin Nutr,* 90**,** 1185-92.

STORK, M. J., KWAN, M. Y., GIBALA, M. J. & MARTIN GINIS, K. A. 2015. Music enhances performance and perceived enjoyment of sprint interval exercise. *Med Sci Sports Exerc,* 47**,** 1052-60.

STYCH, K. & PARFITT, G. 2011. Exploring affective responses to different exercise intensities in low-active young adolescents. *J Sport Exerc Psychol,* 33**,** 548-68.

SVEBAK, S. & MURGATROYD, S. 1985. Metamotivational dominance: a multi-method validation of reversal theory constructs. *J Pers Soc Psychol,* 48**,** 107-116.

TATE, A. K., PETRUZELLO, S. J. & LOX, C. L. 1995. Examination of the relationship between self-efficacy and affect at varying levels of aerobic exercise intensity. *J Appl Soc Psychol,* 25**,** 1922-1936.

TAYLOR, K., WESTON, M. & BATTERHAM, A. 2015. Evaluating Intervention Fidelity: An Example from a High-Intensity Interval Training Study. *PLoS One,* 10**,** 4.

TEMPEST, G. D., ESTON, R. G. & PARFITT, G. 2014. Prefrontal cortex haemodynamics and affective responses during exercise: a multi-channel near infrared spectroscopy study. *PLoS One,* 9**,** e95924.

THACKRAY, A. E., BARRETT, L. A. & TOLFREY, K. 2013. Acute high-intensity interval running reduces postprandial lipemia in boys. *Med Sci Sports Exerc,* 45**,** 1277-84.

THACKRAY, A. E., BARRETT, L. A. & TOLFREY, K. 2016. High-Intensity Running and Energy Restriction Reduce Postprandial Lipemia in Girls. *Med Sci Sports Exerc,* 48**,** 402-11.

TJONNA, A. E., STOLEN, T. O., BYE, A., VOLDEN, M., SLORDAHL, S. A., ODEGARD, R., SKOGVOLL, E. & WISLOFF, U. 2009. Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. *Clin Sci (Lond),* 116**,** 317-26.

TOCCO, F., SANNA, I., MULLIRI, G., MAGNANI, S., TODDE, F., MURA, R., GHIANI, G., CONCU, A., MELIS, F. & CRISAFULLI, A. 2015. Heart Rate Unreliability during Interval Training Recovery in Middle Distance Runners. *J Sports Sci Med,* 14**,** 466-472.

TOWNSEND, N., WICKRAMASINGHE, K., WILLIAMS, J., BHATNAGAR, P. & RAYNER, M. 2015. Physical Activity Statistics 2015. British Heart Foundation: London.

TREASURE, D. C. & NEWBERY, D. M. 1998. Relationship between Self-Efficacy, Exercise Intensity, and Feeling States in a Sedentary Population during and Following an Acute Bout of Exercise. *J Sport Exerc Psychol,* 20**,** 1-11.

TRITTER, A., FITZGEORGE, L., CRAMP, A., VALIULIS, P. & PRAPAVESSIS, H. 2013. Self-efficacy and affect responses to Sprint Interval Training. *Psychol Sport and Exerc,* 14**,** 886-890.

TSCHAKERT, G. & HOFMANN, P. 2013. High-intensity intermittent exercise: methodological and physiological aspects. *Int J Sports Physiol Perform,* 8**,** 600-10.

TUCKER, W. J., SAWYER, B. J., JARRETT, C. L., BHAMMAR, D. M. & GAESSER, G. A. 2015. Physiological Responses to High-Intensity Interval Exercise Differing in Interval Duration. *J Strength Cond Res,* 29**,** 3326-35.

UTTER, A. C., ROBERTSON, R. J., NIEMAN, D. C. & KANG, J. 2002. Children's OMNI Scale of Perceived Exertion: walking/running evaluation. *Med Sci Sports Exerc,* 34**,** 139-44.

VAN DER HORST, K., PAW, M. J., TWISK, J. W. & VAN MECHELEN, W. 2007. A brief review on correlates of physical activity and sedentariness in youth. *Med Sci Sports Exerc,* 39**,** 1241-50.

VALANTINE, I., MADIC, D. & SPORIS, G. 2017. Effects of invasion games on physical fitness in primary school children. *EQOL,* 9**,** 15-22.

VAN LANDUYT, L. M., EKKEKAKIS, P., HALL, E. E. & PETRUZZELLO, S. J. 2000. Throwing the mountains into the lakes: On the perils of nomothetic conceptions of the exercise-affect relationship. *J Sport Exer Psychol,* 22**,** 208–234.

VAN SLUIJS, E. M. F., MCMINN, A. M. & GRIFFIN, S. J. 2007. Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. *BMJ,* 335**,** 703.

WANKEL, L. M. 1993. The importance of enjoyment to adherence and psychological benefits from physical activity. *Int J Sport Psychol,* 24**,** 151-169.

WEINER, B. 1986. An attributional theory of motivation and emotion. New York: Springer-Verlag.

WEISS, M. R., MCAULEY, E., EBBECK, V. & WIESE, D. M. 1990. Self-Esteem and Causal Attributions for Children's Physical and Social Competence in Sport. *J Sport Exerc Psychol,* 12**,** 21-36.

WESTON, K. L., AZEVEDO, L. B., BOCK, S., WESTON, M., GEORGE, K. P. & BATTERHAM, A. M. 2016. Effect of Novel, School-Based High-Intensity Interval Training (HIT) on Cardiometabolic Health in Adolescents: Project FFAB (Fun Fast Activity Blasts) - An Exploratory Controlled Before-And-After Trial. *PLoS One,* 11**,** e0159116.

WILLIAMS, D., DUNSIGER, S., JENNINGS, E. & MARCUS, B. 2012. Does Affective Valence During and Immediately Following a 10-Min Walk Predict Concurrent and Future Physical Activity? *Ann Behav Med,* 44**,** 43-51.

WILLIAMS, D. M. 2008. Exercise, affect, and adherence: an integrated model and a case for self-paced exercise. *J Sport Exerc Psychol,* 30**,** 471-96.

WILLIAMS, D. M., DUNSIGER, S., CICCOLO, J. T., LEWIS, B. A., ALBRECHT, A. E. & MARCUS, B. H. 2008. Acute affective response to a moderate-intensity exercise stimulus predicts physical activity participation 6 and 12 months later. *Psychol Sport Exerc,* 9**,** 231-245.

WORLD HEALTH ORGANISATION (WHO), 2010. Recommendations on Physical Activity for Health, WHO Press, Switzerland.

XU, F. & RHODES, E. C. 1999. Oxygen uptake kinetics during exercise. *Sports Med,* 27**,** 313-27.

YELLING, M., LAMB, K. L. & SWAINE, I. L. 2002. Validity of a Pictorial Perceived Exertion Scale for Effort Estimation and Effort Production During Stepping Exercise in Adolescent Children. *Eur Phy Educ Rev,* 8**,** 157-175.

ZAUBERMAN, G., DIEHL, K. & ARIELY, D. 2006. Hedonic versus informational evaluations: task dependent preferences for sequences of outcomes. *J Behav Decis Mak,* 19**,** 191-211.

ZENKO, Z., EKKEKAKIS, P. & ARIELY, D. 2016. Can You Have Your Vigorous Exercise and Enjoy It Too? Ramping Intensity Down Increases Postexercise, Remembered, and Forecasted Pleasure. *J Sport Exerc Psychol,* 38**,** 149-59.

APPENDIX

Appendix 1: Certificates of ethical approval

Chapter 5

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 160217/B/04

Title: The effect and dose-response-relationship of an acute bout of high-intensity interval running on cardiovascular disease risk factors in adolescents

Applicants: Sascha Kranen, Ricardo Santos Oliveira (PhD), Adam Abdul Malik (PHD), Emma Cockcroft (PhD), Owen Tomlinson (PhD), Dimitris Vlachopoulos (PhD), Kelly Wilkinson (MSc)

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until November 2016

Signature: Date: 15/3/2016

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

Chapter 6 and 8

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree RoadExeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 161207/B/03

Title: Acute psychological, cardiorespiratory and perceptual responses to high-intensity interval exercise differing in work intensity in adolescents

Applicants: Adam Abdul Malik, Owen Tomlinson, Robert Mann, Ricardo Santos Oliveira, Sascha Kranen, Dimitris Vlachopoulos, Lucy Gowing, Max Weston

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until July 2017

Signature: [signature] Date: 17/1/2017

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

Chapter 7 and 8

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 170712/B/02

Title: Perceptual responses and prefrontal cortex oxygenation to high-intensity interval exercise during a 'low to high' and 'high to low' protocol in adolescents.

Applicants: Adam Abdul Malik, Owen Tomlinson, Robert Mann, Ricardo Santos Oliveira, Sascha Kranen, Dimitris Vlachopoulos, Lucy Gowing

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until April 2018

Signature: Date: 09/08/17

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

Appendix 2: Standard health screening form for all experimental chapters

HEALTH SCREEN FOR CHILD VOLUNTEERS (PARENTAL FORM)

Name of child: …………………………………..

Height: …………………………………… (Please provide in cm or feet)

Weight: ………………………………….. (Please provide in kg or stone)

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is:

i) To ensure their own continuing well-being
ii) To avoid the possibility of individual health issues confounding study outcomes

Your answers to the questions in this questionnaire, on behalf of your child, are strictly **confidential**.

Please complete this brief questionnaire to confirm your child's fitness to participate:

1. **At present**, does your child have any health problem for which they are:
   (a) On medication, prescribed or otherwise …………. YES ☐ NO ☐
   (b) Attending a general practitioner …………………. YES ☐ NO ☐
   (c) On a hospital waiting list ………………………… YES ☐ NO ☐

2. **In the past two years**, has your child had any illness that required them to:
   (a) Consult your family GP………………………….. YES ☐ NO ☐
   (b) Attend a hospital outpatient department ………… YES ☐ NO ☐
   (c) Be admitted to hospital…………………………... YES ☐ NO ☐

3. **Has your child ever** had any of the following:
   (a) Convulsions/epilepsy ……………………………. YES ☐ NO ☐
   (b) Asthma ………………………………………….... YES ☐ NO ☐
   (c) Eczema ………………………………………….... YES ☐ NO ☐
   (d) Diabetes ………………………………………….. YES ☐ NO ☐
   (e) A blood disorder …………………………………. YES ☐ NO ☐

(f) Head injury .... YES ☐ NO ☐

(g) Digestive problems .... YES ☐ NO ☐

(h) Heart problems .... YES ☐ NO ☐

(i) Lung problems .... YES ☐ NO ☐

(j) Problems with bones or joints .... YES ☐ NO ☐

(k) Disturbance of balance/coordination .... YES ☐ NO ☐

(l) Numbness in hands or feet .... YES ☐ NO ☐

(m) Disturbance of vision .... YES ☐ NO ☐

(n) Ear/hearing problems .... YES ☐ NO ☐

(o) Thyroid problems .... YES ☐ NO ☐

(p) Kidney or liver problems .... YES ☐ NO ☐

(q) Allergy to nuts .... YES ☐ NO ☐

(r) Eating disorder .... YES ☐ NO ☐

4. Do you know of any other reason why your child should not engage in physical activity?

YES ☐ NO ☐

If **YES** to any question, please describe briefly (for example, to confirm the problem was/is short-lived, insignificant or well controlled).

A member of our research team may contact you if we have any further questions.

Thank you for your cooperation

Primary investigator:
Adam Malik
aa643@exeter.ac.uk
01392 724889

Project coordinators:
Dr. Alan Barker
A.R.Barker@exeter.ac.uk
01392 722766

Professor Craig Williams
c.a.williams@exeter.ac.uk
01392-724890

Appendix 3: Example information pack to participants (Chapter 6)

Participant Information Sheet

Study: Influence of different intensities of cycling exercise on psychological responses in adolescents

Researcher: Adam A. Malik

Organisation: University of Exeter

Version: 1. 17/11/2016

Thank you for your interest. Please read this information carefully and discuss the study with your parents/guardians before deciding whether or not to sign the consent form.

1. What is the purpose of the study?

Performing short bouts of high-intensity exercise may be a useful strategy to promote health in adolescents. Long-term participation in exercise is related to experiencing feelings of pleasure and enjoyment but we know very little about these feelings during high-intensity exercise. This study will investigate how different work rate of cycling exercise may affect your feelings (like/dislike) and enjoyment level. We also want to know how high-intensity exercise alters you breathing rate and heart rate and see if this is linked to how you feel about the exercise.

2. What does this study involve?

All procedures of this study will be conducted in your school. We will set up a temporary laboratory area in a room provided by the school. You will be asked to complete a total of four visits to the temporary laboratory area we have set-up in your school, with each visit lasting approximately 1 hour. Details of each visit are outlined below.

Visit 1

On the first visit, we will give you another detailed explanation of the study and the tests that we will ask you to complete. We will then measure your body weight and height, followed by a measurement of the fold of your skin in different regions of your body to calculate your body fat. You will then be asked to cycle on a bike to make sure you feel comfortable with it. We will then ask you to complete a test on the cycle ergometer which involves cycling until you are exhausted. Every minute we will increase the work rate of the cycling until you are too tired to cycle. During the test you will wear a facemask so that we can measure the oxygen your body is using to complete the exercise. We will also attach some electrodes to your chest to measure your heart rate. After a short break, you will be asked to complete another cycling test at a work rate slightly higher than the first test. After completing these tests, we will then show you all the measurements we will ask you to complete during visits 2-4. At the end of the visit you will be asked to wear a watch-like device (accelerometer) for a period of seven days. This watch will tell us how much exercise you perform during a typical week.

Visit 2-4

During these visits you will be asked to complete one of three differences cycling tests ranging from 70% to 110% of the maximum work-rate you achieved in visit 1:

1. High-intensity (70% of work rate): You perform 8 x 1 minute intervals of high-intensity cycling on the cycling separated by 75 seconds of light cycling.
2. High-intensity (90% of work rate): You perform 8 x 1 minute intervals of high-intensity cycling on the cycling separated by 75 seconds of light cycling.
3. High-intensity (110% of work rate): You perform 8 x 1 minute intervals of high-intensity cycling on the cycling separated by 75 seconds of light cycling.

Before, during, and after the exercise/rest condition, you will be asked to complete some questionnaires and measuring scales about your how hard you found the exercise and your enjoyment levels. Bear in your mind, there is no or right answer for all the questions that will be asked.

3. How long I need to involve with this study?

You will involve with this study with approximately 3 – 4 weeks. Following the visit 1 (approximately 1 week after), you will need to complete three cycling exercise (visits 2, 3 and 4) in randomized order and on separate days. All the visits will be separated with a minimum of two days each.

4. What else do I have to do?

During all visits you will have to cycle on a cycle ergometer, therefore you will need to bring suitable kit for exercise (shorts, t-shirt and trainers).

We would also encourage you to ask as many questions as you please. We hope that your participation in the project inspires you to think about your health and the potential of higher education.

5. What are the possible risks for me if I decide to take part?

All the procedures used in the study are regularly used in research with children and adolescents. The minimal risks include some tiredness after the incremental cycling test and you may feel light muscle pain in the days following the test. The completion of a health assessment form by you, together with your parents, prior to the study, will ensure your safety to participate.

6. What will be my gains from taking part in this study?

This study will look at how different exercise intensities influence your feeling and enjoyment responses. Whilst this may not immediately benefit you, we hope that you will enjoy your participation in the project and the chance to be part of a scientific study. At the Children’s Health and Exercise Research Centre, we pride ourselves on ensuring that each volunteer has an enjoyable and informative experience throughout every research project. We hope that we can inspire you to take an interest in your health and in the science of exercise, and that this project will be both interesting and fun.

7. What will happen to the results of the study?

Your data will be stored in coded form to protect anonymity and will be completely confidential. This research will form part of a PhD thesis, and this study will also be submitted to relevant scientific journals for publication. Your information and data will not be identifiable in either of these instances. You will be sent a summary of the research findings once all data have been collected and analysed, as well as your individual data with a full explanation of what it represents should you so wish.

8. What should I do if I would like to take part?

Please note that your participation must be decided together with your parents. If you would like to take part in the study you and your parents must give your permission by completing the following forms which are included in this information pack.

- The contact information form
- The parental consent form
- The participant assent form
- The health screen questionnaire

You should then return these forms to the school reception. We will then make contact with the teachers and the school to arrange the schedule for tests.

Taking part is entirely voluntary and it is up to you to decide whether or not you will be involved. If you want to take part you are still free to withdraw at any time, without giving a reason. If you have any questions regarding the nature or purpose of this study, please feel free to us on our details below.

Primary investigator:
Adam Malik
aa643@exeter.ac.uk
01392 724889

Project coordinators:
Dr Alan Barker
A.R.Barker@exeter.ac.uk
01392 722766

Professor Craig Williams
c.a.williams@exeter.ac.uk
01392-724890

Parent/Guardian Consent Form

Study: Influence of different intensities of cycling exercise on psychological responses in adolescents
Researcher: Adam A. Malik
Organisation: University of Exeter
Version: 1. 17/11/2016

I have read the information sheet, version V1.17/11/2016, regarding this project and understand the rationale for the study and what my child will be asked to do. I have had the chance to ask questions about the study, and I have received satisfactory answers to any questions I have asked.

Please put your initials in the small boxes to indicate you understand that:

- My child will complete four days of tests and he/she can withdraw whenever he/she wants. ☐
- My child will have his/her height, weight, and body fat measured. ☐
- My child will assess their own pubertal status by using scientific drawings of secondary sexual characteristics. The purpose of this has been made clear to me. ☐
- My child will be asked to complete an incremental cycling test on a cycle ergometer until exhaustion. ☐
- My child will participate in three cycling trials at different intensities. ☐
- My child will answer questions about feelings of like or dislike, feelings of exertion and enjoyment before, during and after the exercise bouts. ☐
- My child will answered all the questions as accurate as he can without any interference from researcher. ☐

- My child will be asked to wear an accelerometer (a device to measure his/her physical activity levels) for seven days, Saturday and Sunday included. ☐

- I am free to request further information at any stage. ☐

I know that:

- My child's participation in the project is entirely voluntary and he/she is free to withdraw from the project at any time without giving reason. ☐

- The results will be stored confidentially on a computer for sole use by the Children's Health and Exercise Research Centre, University of Exeter. ☐

- The results of the project may be published but my child's anonymity will be preserved. ☐

Name: …………………………………………………………

Signed: …………………………………………………………. (Parent/Guardian)

Date: ………………………………………………………….

On behalf of my child: ……………………………………………

Name: …………………………………………………………

Signed: …………………………………………………………. (Researcher)

Date: ………………………………………………………….

Participant Consent Form (to be completed by the child)

Study: Influence of different intensities of cycling exercise on psychological responses in adolescents

Researcher: Adam A. Malik

Organisation: University of Exeter

Version: 1. 17/11/2016

I agree to take part in the study as described in the information sheet version 1. 17/11/2016. The study has been clearly explained to me and I have had the opportunity to ask any questions I may have about my involvement in the study.

Please write your initials in the small boxes to indicate you understand that:

- I will complete four days of tests and I can withdraw from them whenever I want to. ☐
- I will have my height, weight, and body fat measured. ☐
- I will assess my pubertal status by using scientific drawings of secondary sexual characteristics. The purpose of this has been made clear to me. ☐
- I will be asked to complete an incremental cycling test on a cycle ergometer until exhaustion. ☐
- I will participate in three cycling trials at different intensities. ☐
- I will answer questions about feelings of like or dislike, feelings of exertion and enjoyment before, during and after the exercise bouts. ☐
- I will answer all the questions given to me as accurate as I can without any interference from researcher. ☐
- I understand that there is no or right answer to the questions that I will be given. ☐

- I will be asked to wear an accelerometer, a device that will measure my physical activity levels, for seven days, Saturday and Sunday included. ☐
- I am free to ask any questions at any time. ☐

I know that:

- I can withdraw from the study at any point with no questions asked. ☐

Name ……………………………………………………………………….

Signed ……………………………………………………………………….

(Participant)

Date ……………………………………………………………………….

Name ……………………………………………………………………….

Signed ……………………………………………………………………….

(Researcher)

Date ……………………………………………………………………….

Study: Influence of different intensities of cycling exercise on psychological responses in adolescents

Researcher: Adam A. Malik

Organisation: University of Exeter

Version: 1. 17/11/2016

Contact details

Child's name: ____

Parent's/guardian's name: ____________________________________

Address: ______________________________________

____

Postcode:____

Home telephone: ____

Mobile telephone: ____

Email address: ____

Best time to contact you: _____________________________________

Appendix 4: Physical Activity Enjoyment Scale (PACES) questionnaire

Physical Activity Enjoyment Scale (PACES)

ID : ………………………………. GENDER :………………….

Age : ……………………………… YEAR:………………………

Please rate how you feel at this moment about the exercise you have been doing

		Disagree a lot	Disagree a little	Neither agree nor disagree	Agree a little	Agree a lot
1	I enjoy it	**1**	**2**	**3**	**4**	**5**
2	1 feel bored	**1**	**2**	**3**	**4**	**5**
3	I dislike it	**1**	**2**	**3**	**4**	**5**
4	I find it pleasurable	**1**	**2**	**3**	**4**	**5**
5	It's no fun at all	**1**	**2**	**3**	**4**	**5**
6	It gives me energy	**1**	**2**	**3**	**4**	**5**
7	It makes me depressed	**1**	**2**	**3**	**4**	**5**
8	It's very pleasant	**1**	**2**	**3**	**4**	**5**
9	My body feels good	**1**	**2**	**3**	**4**	**5**
10	I get something out of it	**1**	**2**	**3**	**4**	**5**
11	It's very exciting	**1**	**2**	**3**	**4**	**5**
12	It frustrates me	**1**	**2**	**3**	**4**	**5**
13	It's not at all interesting	**1**	**2**	**3**	**4**	**5**
14	It gives me a strong feeling of success	**1**	**2**	**3**	**4**	**5**
15	It feels good	**1**	**2**	**3**	**4**	**5**
16	I feel as though I would rather be doing something else	**1**	**2**	**3**	**4**	**5**

Appendix 5: Exercise task self-efficacy questionnaire

Exercise task Efficacy

ID : ………………………………. **GENDER :………………….**

Age : ……………………………… **YEAR:…………………**

In answering the following questions think about **HOW CONFIDENT** you are **in performing the exercise that you just did**

Using the scale below, please check the appropriate response (0-100%) for each question. There are **5 questions** in total to be answered.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Not at all confident			Really not confident		Kind of confident		Reasonably confident		Almost confident	Completely confident

1. How confident are you that you can perform **ONE** bout of exercise a week for the next 4 weeks that is just like the one you completed today?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

2. How confident are you that you can perform **TWO** bouts of exercise a week for the next 4 weeks that is just like the one you completed today?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

3. How confident are you that you can perform **THREE** bouts of exercise a week for the next 4 weeks that is just like the one you completed today?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

4. How confident are you that you can perform **FOUR** bouts of exercise a week for the next 4 weeks that is just like the one you completed today?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

5. How confident are you that you can perform **FIVE** bouts of exercise a week for the next 4 weeks that is just like the one you completed today?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Appendix 6: Behavioural activation and behavioural inhibition questionnaire

ID : ……………………………….. **GENDER :………………….**

Age : ……………………………… **YEAR :…………………**

Behavioural Activation & Behavioural Inhibition System

Each item of this questionnaire is a statement that a person may either agree with or disagree with. For each item, indicate how much you agree or disagree with what the item says. Please respond to all the 24 items (; do not leave any blank. Choose only one response to each statement. Please be as accurate and honest as you can be. Respond to each item as if it was the only item. That is, don't worry about being "consistent" in your responses. Choose from the following four response options:

1 = very true for me
2 = somewhat true for me
3 = somewhat false for me
4 = very false for me

1	A person's family is the most important thing in life.	1	2	3	4
2	Even if something bad is about to happen to me, I rarely experience fear or nervousness.	1	2	3	4
3	I go out of my way to get things I want.	1	2	3	4
4	When I'm doing well at something I love to keep at it	1	2	3	4
5	I'm always willing to try something new if I think it will be fun.	1	2	3	4
6	How I dress is important to me.	1	2	3	4
7	When I get something I want, I feel excited and energized.	1	2	3	4
8	Criticism or scolding hurts me quite a bit.	1	2	3	4
9	When I want something I usually go all-out to get it.	1	2	3	4

10	I will often do things for no other reason than that they might be fun.	1	2	3	4
11	It's hard for me to find the time to do things such as get a haircut.	1	2	3	4
12	If I see a chance to get something I want I move on it right away.	1	2	3	4
13	I feel pretty worried or upset when I think or know somebody is angry at me.	1	2	3	4
14	When I see an opportunity for something I like, I get excited right away.	1	2	3	4
15	I often act on the spur of the moment	1	2	3	4
16	If I think something unpleasant is going to happen, I usually get pretty "worked up."	1	2	3	4
17	I often wonder why people act the way they do.	1	2	3	4
18	When good things happen to me, it affects me strongly.	1	2	3	4
19	I feel worried when I think I have done poorly at something important.	1	2	3	4
20	I crave excitement and new sensations	1	2	3	4
21	When I go after something I use a "no holds barred" approach	1	2	3	4
22	I have very few fears compared to my friends.	1	2	3	4
23	It would excite me to win a contest.	1	2	3	4
24	I worry about making mistakes.	1	2	3	4

Appendix 7: Standard anthropometric assessment form

Individual data form (Visit 1; Date :……………..)

ID		
D.O.B		
Height (cm)		
Weight (kg)		
Dominant Hand	**Right ( )**	**Left ( )**

Skinfold measurement

Triceps (mm)			
Subscapular (mm)			

Face mask size: …………………………

Seat height   : ………………………....

Peak Power output (Watts):……........

Appendix 8: Standard perceptual and heart rate responses form during ramp test

ID : ……………………………　　　**GENDER: ………………….**

Age : ………………………………　　　**YEAR: ……………………...**

Ramp Test　　　**Recovery (5 min)**

Time (min)	RPE	FS	FAS	HR		Time (min)	RPE	FS	FAS	HR
1						1				
2						2				
3						3				
4						4				
5						5				
6										
7										
8										
9										
10										
11										
12										
13										
End test										

Appendix 9: Standard perceptual and heart rate responses form during HIIE

Experimental Test (HIIE :………..) (Visit 2/3/4; Date ……………)

ID : ………………………………. **GENDER:………………….**

Age: ……………………………… **YEAR:…………………**

Work							Recovery				
Time (min)	**RPE**	**FS**	**FAS**	**EES**	**HR**		**RPE**	**FS**	**FAS**	**EES**	**HR**
Pre 5min											
End warm-up											
1											
2											
3											
4											
5											
6											
7											
8											
End Cool down											
Post 20 min											