

Exercise-induced Changes in Affective Valence; Relevance, Mechanisms, and Predictors

by

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I dedicate this thesis to my mental health journey and the strength I have shown to make it here.

Declaration

I declare that this thesis was composed by myself and that all the data were collected and analysed by myself, under the supervision of Dr. Sinead Currie and Dr. Niels BJ Vollaard, with the following exceptions:

1. The original R studio script and statistical advice used for the meta-analysis in **Chapter 2** was written and provided by Dr. Iain Gallagher at Edinburgh Napier University, this code was adapted by myself for the final analysis.
2. 18 of the participants recruited for the psychological traits as potential predictors of AV change experiment in **Chapter 4** were recruited by Dr. Richard S Metcalfe at Swansea University.

Neither the thesis, nor the original work contained therein have been submitted to this or any other institution for a higher degree. This thesis does not infringe upon anyone's copyright and any material from the work of others included in this thesis are fully acknowledged in accordance with common reference practices.

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Abstract

Global physical activity (PA) levels are decreasing, leading to a greatly increased risk of premature morbidity. It is proposed that changes in affective valence (AV) during exercise may moderate uptake of and adherence to exercise, through a hypothesised pathway. Decreases in AV during exercise are linked to reduced remembered exercise enjoyment and reduced remembered exercise enjoyment is linked with reduced uptake of and adherence to exercise. Identifying what factors may influence AV change during exercise may be key to moderating AV responses and promoting increase uptake of and adherence to exercise. Therefore, the overall aim of this thesis is to elucidate what affects the change in AV during different types of exercise and how this is linked to exercise enjoyment levels.

Chapter 1 provides a comprehensive overview of the available literature within the field and context of this thesis. **Chapter 2** meta-analyses available literature to identify the credibility of the hypothesis of the DMM, particularly that exercise at intensities below 100% of the VT elicit a homogenous positive AV response. **Chapter 3** follows with a human trial assessing the relationship between changes in AV during exercise and remembered exercise enjoyment, by comparing exercise bouts of varying durations and intensities. The final experimental chapter, **chapter 4**, assesses the variability of AV responses to low-volume SIE within and between individuals and attempts to identify any potential associations between the change in AV during exercise and psychological characteristics. **Chapter 5** discusses the findings of the aforementioned chapters in a broader scope and addresses future directions of research.

Overall, this thesis contributes to the available literature concerning AV change during exercise, critically evaluating long-standing theories, identifying important relationships, and assessing potential moderating factors of AV change.

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List of Publications/ Conference activity

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Vollaard NBJ, Metcalfe RS, **Kinghorn DJ**, Jung ME, Little JP (2024). Percentage of Peak Workload Is Suitable for Quantification of Exercise Intensity During High-Intensity Intervals: A Comment on Ekkekakis, Hartman, and Ladwig. *J Sport Exerc Psychol*, 46 (2): 63-65.

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November 2024 (oral presentation): British Association for Sport and Exercise Sciences in Coventry, United Kingdom. Title: A comparison of affective responses during continuous and sprint interval exercise.

List of Abbreviations

AMPK- Adenosine monophosphate-activated protein kinase

ASI-3- Anxiety sensitivity index

AUC- Area-under-the-curve

AV- Affective valence

β -HAD- 3- β -hydroxyacyl CoA dehydrogenase

[La-]b- Blood lactate concentration

BMI- Body mass index

BPQ- Body perception questionnaire

CS- Citrate synthase

DMM- Dual-mode model

EEG- Electroencephalography

ELPD-LOO- Expected log pointwise predictive density leave one out

EPO- End power output

FA- Felt arousal

FS- Feeling scale

HDI- High density intervals

HIIE- High-intensity interval exercise

HR- Heart rate

HRV- Heart rate variability

IPAQ- International physical activity questionnaire

LT- Lactate threshold

MAPK- p38 mitogen activated protein kinase

MPO- Mean power output

MICE- Moderate-intensity continuous exercise

PA- Physical activity

PACES- Physical activity enjoyment scale

PAR-Q- Physical activity readiness questionnaire

PGC- 1 α - Peroxisome proliferator-activated receptor- γ coactivator 1- α

PFC- Prefrontal cortex

PI- Physical inactivity

PPO- Peak power output

PRISMA- Preferred reporting items for systematic reviews and meta-analyses

PRETIE-Q- Preference for and Tolerance of the Intensity of Exercise Questionnaire

PSIS-LOO- Pareto smoothed importance sampling leave-one-out

RCP- Respiratory compensation point

REHIT- Reduced-exertion high-intensity training

RER- Respiratory exchange ratio

RPE- Rating of perceived exertion

SD- Standard deviation

SIE- Sprint interval exercise

SOA- Sense of agency

TCA- Tricarboxylic acid cycle

VE/ $\dot{V}O_2$ -Ventilatory equivalents for oxygen

$\dot{V}E/\dot{V}CO_2$ - Ventilatory equivalents for carbon dioxide

VT- Ventilatory threshold

VO_{2max} - Volume of oxygen (maximal)

W- Watts

WHO- World health organisation

Wingate-based HIT- High intensity training

Chapter 1- Introduction to Thesis

1.1: Physical Inactivity

The effects of maintaining good physical health are well evidenced (Blair and Morris, 2009; Pedersen and Saltin, 2015; Booth et al., 2017; Warburton and Bredin, 2017; Malm, Jakobsson and Isaksson, 2019). Physical inactivity (PI) has been attributed as the leading cause of 35 chronic conditions, including type-2 diabetes and coronary heart disease (Booth et al., 2012; Gillett et al., 2012; Booth et al., 2017), with coronary heart disease and type-2 diabetes projected to be the 1st and 7th leading cause of death globally by 2030 (Mathers and Loncar, 2006; Abu-Rmeileh et al., 2012; Booth and Hawley, 2015). The World Health Organisation (WHO) currently recommends that adults reach a minimum of 150-300 min moderate intensity physical activity (PA), 75-150 min vigorous intensity PA, or an equivalent combination of both each week (Bull et al., 2020). The WHO also recommend that adults perform muscle strengthening activities at a moderate, or greater, intensity involving all major muscle groups at least twice a week. Global evidence has shown that at least 27.5% of individuals (2.2 billion individuals) do not achieve the currently recommended PA guidelines (Guthold et al., 2018; Ozemek, Lavie, and Rognmo, 2019; Strain et al., 2020; Hall et al., 2022), with regionally focussed studies in the United States finding these numbers to be even higher between 74.7% and 90.4% (Tucker et al., 2011; Whitfield et al., 2019). A survey of 298 populations from 146 countries (1.6 million participants) found that 81% of 11–17-year-olds are not sufficiently active (Guthold et al., 2020). In 2016, the prevalence of PI in high-income countries was 36.8%, more than double the 16.2% of the low-income countries in the study (Guthold et al., 2018). Conditions caused by inactivity are estimated to cost the United Kingdom National Health Service (UK NHS) between £800 million in the fiscal year 2016-17 (Heron et al., 2019), and £900 million in the fiscal year 2018-19 with a total estimated £7.4 billion cost to the entire UK economy (NHS Digital, 2020). The WHO estimates that the treatment of non-communicable conditions, of what PI is a leading cause, will total \$300 billion by 2030, estimated at roughly \$27 billion annually (World Health Organisation, 2022). It is also estimated that one in every six

deaths in the UK annually, 70,000 individuals, could be avoided if the population were sufficiently active (Heron et al., 2019; NHS Digital, 2020). Evidence has shown that 3-15% of all premature deaths worldwide are caused by PI (Lee et al., 2012; Rezende et al., 2019; Strain et al., 2020; Katzmarzyk et al., 2022). High-income countries suffer the greatest financial burden to healthcare systems and highest population inactivity per-capita, with medium-income countries bearing the largest number of individuals suffering from a PI related disease (Ding et al., 2016; Katzmarzyk et al., 2022). Individuals sitting at a desk for the duration of their working life are at a much greater risk of becoming sedentary and increasing their health risks (Brown et al., 2003; Miller and Brown, 2004). However, those who meet PA guidelines outside of sitting time show greatly reduced mortality rates in comparison to those not achieving PA guidelines with lower sitting time (Ekelund et al., 2016; Wanner et al., 2016). Individuals with desk-based work lives can still avoid the effects of PI by reaching PA guidelines out with their work commitments.

1.2: Reasons for PI

There are a multitude of potential given reasons for PI (Rutten et al., 2009; Costello et al., 2011; Pengpid and Peltzer, 2013; Hoare et al., 2017), with Bauman et al (2012) producing an ecological multi-level model of the determinants of PA which spanned intrapersonal, interpersonal, environmental, political, and global factors. Access to the education and facilities required to lead a healthy lifestyle, tend to be a greater issue in lower income regions (Haase et al., 2004). As well as this, access to walkable green spaces, cycling lanes in cities, public swimming pools and gyms, and alternative exercise spaces such as rock climbing and trampoline parks have been shown to have an impact on PA levels and obesity rates (Samir et al., 2011; Knobel et al., 2021), though a study by Villaneuva et al (2016) found that facility availability was only associated with obesity rates, not PI levels, in Spanish children. Societal issues have also caused individuals, particularly women, to feel unsafe walking alone in public parks and other exercise routes after dark due to fears of personal harm (Reinhold et al., 2024).

Biological factors that can limit exercise participation include various genetic conditions and physiological differences that range in severity, from preventing the ability to perform exercise altogether to increasing the risk of damage to certain joints, tissues, or organs (WHO, 2011). Ginis et al (2021) found that individuals living with a disability are 16-62% less likely to meet PA levels than people living without disabilities. These factors require more specialised help to ensure activity levels are being met (WHO, 2011; Ginis et al., 2021). For biological females, negative PA habits can occur due to pregnancy (pre- and post-partum), with education on exercising while pregnant not commonly promoted, leading to greater reduced PA levels after the discovery of the pregnancy (Melzer et al., 2010). Only 23-29% of US women met PA guidelines during the gestational phase (Hesketh and Evenson, 2016), with low energy levels and a perceived lack of time given as common barriers preventing women from returning to previous PA levels post-partum (Borodulin et al., 2009; DiPietro et al., 2019). A study conducted across 28 European countries found women were less likely to participate in vigorous intensity exercise, moderate intensity exercise, and sport when compared to men, with no difference in walking (Owen et al., 2025). The gap in activity levels decreased between 2005 and 2022 for vigorous activity but widened further with moderate intensity exercise. The gap in gender participation rates for sport also increased between 2009 and 2022 (Owen et al., 2025). Age is another biological factor that influences PA levels, with PA rates greatly decreasing in adults over 50 (Sun et al., 2013; Sparling et al., 2015; McPhee et al., 2016). The benefits of maintaining all forms of training, from resistance to aerobic, into the later stages of adult life are evidenced, postponing the onset of multiple conditions, potentially by years (Taylor, 2014; Sparling et al., 2015; Macera et al., 2017). However, as an individual's age increases, so does the difficulty of maintaining mobility and strength, as well as an increased risk of injuries (Franco et al., 2015; Musich et al., 2018). This, in part, has resulted in only 25% of English adults aged 65 or older meeting the minimum PA guidelines (McPhee et al., 2016).

Psychological and psycho-social factors are also theorised to impact on exercise adherence. One's perception of their physical autonomy, their ability to complete a given physical task (Robinson et al., 2015; Estevan and Barnett, 2018), has been shown to impact exercise rates in both children and adults, as the

belief of whether the task can be accomplished, or not, can prevent individuals from even wanting to attempt the task (Stodden et al., 2008). Lower levels of self-efficacy, one's belief in their ability to perform tasks to an adequate level (Bandura, 1994), when exercising negatively impacts exercise uptake and adherence rates as individuals fear social criticism and rejection (Zhi et al., 2023). Low self-efficacy during exercise has been shown to be more prevalent in females compared to males, especially in adolescents (Pender et al., 2002), as well as in individuals with an above average body fat percentage and 'overweight' or above body mass index (BMI) classification (Brooks et al., 2018). Motivation to exercise is also impacted upon by interpersonal factors, such as family habit (Mulhall et al., 2011), with nurtured PA habits during childhood and adolescence being shown to continue into adolescence and adulthood (Malina, 2001). Adolescents with greater family and school cohesion are likely to have greater PA levels, and active adolescents with poor cohesion are more likely to become inactive over two years (Pabayo et al., 2014). Despite the multitude of potential reasons that have just been described, a perceived lack of time is the most commonly attributed reason for adult individuals not exercising sufficiently (Troost et al., 2002; Nomaguchi and Bianchi, 2004; Korkiakangas et al., 2009; Louw, Van Biljon, and Mugandani, 2012; Baillot et al., 2021; Ilić et al., 2024). Work-life balance and the necessary commutes, childcare, and relaxation time from the stresses of life, particularly for lower-income individuals, have all been cited as reasons people do not feel they have the time to exercise (Withall et al., 2011). This claim has been disputed though. Ekkekakis et al (2023) suggest that while a lack of time is the undisputed most common perceived reason for inactivity, the truth is that people chose to spend what discretionary time they have available on sedentary pursuits. Multiple studies have shown that time commitment does not have an impact on exercise adherence and dropout rates (Perri et al., 2002; Jakicic et al., 2003; Church et al., 2007; Rhodes et al., 2009), and it has been shown that leisure time in adults in the United States has increased by 6.2 hrs per week for working men (from ~3 hrs to ~9 hrs) and 4.9 hrs per week for working women (from ~4 hrs to ~8hrs) between 1965 and 2003 (Aguiar and Hurst, 2007; Aguiar et al., 2012). Ekkekakis et al (2023) suggest that the universal increase in screen related sedentary activities filling this time is more of the cause than there not being enough total time (Gimenez-Nadal and Sevilla, 2012). Kahneman et al (2004) found that, when removing all necessary non-work

activities, American adults averaged a mean ‘free time’ of over 5 hours a day, with no sub-group averaging less than 4.5 hours, however men only averaged 24 min PA daily with women averaging 14 min, leading to studies concluding that a lack of time is not responsible for inactivity levels (Sturm and Cohen, 2019; Rebar et al., 2019). How the time is being used, and why individuals feel the need to do activities that are screen related and sedentary, is a much broader behavioural psychology question that is beyond the scope of this thesis.

Whether or not a lack of time is a valid reason for PI will continue to be debated, but the *perceived* lack of time means that many individuals do not adhere to the often-advised form of exercise ‘moderate intensity continuous exercise’ (MICE). MICE protocols are exercise bouts during which improvements to aerobic fitness are achieved through activity that can be maintained continuously, uses large muscle groups, and is considered naturally rhythmic (Patel et al 2017). The WHO recommends that individuals exercise at a moderate intensity for 150 min a week, commonly split into 5 x 30-min exercise bouts, as one of the ways to achieve the minimum PA guidelines (Piercy et al., 2018; Jakicic et al., 2019; Bull et al., 2020). It is currently unknown whether exercise protocols with reduced time-commitments can remove the barrier of a perceived lack of time, especially if the existence of that perceived lack of time is disputed, but research into alternative exercise interventions began investigating whether drastically reducing the exercise bout duration while drastically increasing the peak exercise intensity of the bout could achieve the aim of improving aerobic physical fitness in a shorter time.

1.3: The origins of High-Intensity Interval Exercise (HIIE) and Sprint

Interval Exercise (SIE)

Personal memoirs of Finnish Olympic athletes from over 100 years ago incorporating interval training into their event preparations for the 1912 Olympics are some of the earliest mentions of HIIE. The Finnish coach Lauri Pikhala advised two athletes to include training that alternates fast runs with slow runs, and to finish off with sprints. This way of training was not adopted by the rest of the world until the mid-1930s when

Swedish coach Gosta Holmer developed 'fartlek training'. The intensity of this training protocol was dependent on how the athlete feels, with the speed varying throughout a session. This protocol was used to great success by middle distance runners in the pre-World War two era (Kelemen et al., 2024). At a similar time to Holmer, German coach Woldemar Gerschler and Dr Herbert Reindel devised an interval training method that was prescribed using an individual's heart rate (HR; Gibala and Hawley, 2017). Individuals would stress the heart until the HR reached 180 beats per minute (BPM) before allowing 1 min 30 s rest to allow the HR to return to 120-125 BPM. The training consisted typically of shorter distance runs of 100 metres to 200 metres, and the session was concluded after the HR could not return to 120-125 BPM after the recovery. Gerschler advocated for increasing the distance and reducing the recovery to progress the training, as opposed to increasing the running pace. Post-World War two, the emergence of Czech long-distance runner Emil Zatopek further promoted interval training as a legitimate method for improving aerobic fitness. Zatopek would break his long-distance runs (which are documented to be between 600-935 kilometres (km) a month during the running season) into much shorter bouts at a higher intensity, with recovery jogs in between (Fortune, 2022). With this method of training Zatopek won gold in the 5 km, 10 km, and marathon at the 1952 Olympics. A decade later, Swedish physiologist Per-Olof Astrand showed that, using a cycle ergometer, interval training with adequate rest allowed individuals to perform the same overall volume of exercise at a higher intensity (Astrand et al., 1960).

In the 1970s a cycle ergometer test was developed at the Wingate institute to measure an individual's anaerobic power and capacity (Inbar et al., 1976). The test involves 30 s supramaximal cycling against a resistance of 7.5% of the individual's body mass. It has been a commonly used fitness test worldwide since its creation (Katz et al., 1984; McKenna et al., 1997; Burgomaster et al., 2005; Gibala et al., 2006; Metcalfe et al., 2012) and is the basis of most cycle ergometer SIE protocols. In the decades following the development of the Wingate sprint, multiple studies investigated the effects of 8-10 x 30 s Wingate sprints on physiological factors, such as anaerobic and oxidative enzyme activity and other metabolic outcomes (Katz et al., 1984; Sharp et al., 1986; Jacobs et al., 1987; Stathis et al., 1994; McKenna et al., 1997;

MacDougall et al., 1998; Harmer et al., 2000), with several studies reporting increases to aerobic capacity ($\text{VO}_{2\text{max}}$) with this protocol (Katz et al., 1984; McKenna et al., 1997; MacDougall et al., 1998; Harmer et al., 2000). Interestingly, Allemeier et al., (1994) reported a 14% increase to $\text{VO}_{2\text{max}}$ in a protocol with just three repeated Wingate sprints per session but this did not receive much attention at the time. Similarly, during the 1990s, another HIIE protocol was being developed in Japan. Tabata et al (1996) found that MICE significantly improved athletes' aerobic capacity but did not significantly improve anaerobic capacity, and that a training protocol consisting of seven or eight 20 s exercise bouts at 170% of $\text{VO}_{2\text{max}}$ (with 10 s rest in between) on a mechanically braked cycle ergometer significantly improved both (anaerobic capacity increased 28%, $\text{VO}_{2\text{max}}$ increased 13%). Much of the early research described here into SIE was conducted in athletic or recreationally active populations, with less of a focus given to inactive or sedentary populations, which at the time limited the feasibility of this type of exercise being recommended for those populations.

Following the success of Tabata's protocol and the initial Wingate-based high-intensity training (HIT), combined with the perceived need for a time-efficient exercise protocol, research into the usage of SIE within a public health setting as an alternative to MICE began in the early 2000s. It had been shown that aerobic metabolism contributes significantly to repeated sprint performance (Bogdanis et al., 1996; Trump et al., 1996; McKenna et al., 1997; Parolin et al., 1999), and that 6-8 week sprint based training protocols showed increases in enzyme activity associated with oxidative capacity (Jacobs et al 1987; MacDougall et al., 1998). However, the 8-10 sprint Wingate-based HIT protocols took at least 35 min to complete with adequate recovery periods and were severely fatiguing. Barnett et al (2004) were the first to introduce the 'classic SIE' protocol of up to six repeated 30 s Wingate sprints. They reported an 8% increase to $\text{VO}_{2\text{max}}$ and a 42% increase to citrate synthase (CS; an oxidative enzyme) activity following 8 weeks of three sessions progressing from three 30 s sprints in weeks 1 and 2 to 6 in weeks 7 and 8, increasing by 1 sprint per session each week. As well as this, Rodas et al (2000) and Parra et al (2000) identified significant improvements to $\text{VO}_{2\text{max}}$ and CS activity with two weeks of daily sprint exercise (a combination of 15 s

sprints with 45 s rest and 30 s sprints with 12 min rest, increasing from 2 of each sprint duration for the first three sessions to 7 of each in the final session) in healthy male participants. Parra et al (2000) found that peak power output (PPO) and mean power output (MPO) remained unchanged in the daily sprint protocol but in the 6-week intervention (1-2 days rest between sessions) power output significantly improved. These findings promoted Martin Gibala, an expert in oxidative metabolism focusing on the tricarboxylic acid cycle (TCA cycle), and the impact of exercise on its function (Gibala and Saltin, 1999; Gibala et al., 2002; Baldwin et al., 2003; Dawson et al., 2003; Howart et al., 2004), and his team at McMaster University to assess whether a reduced-volume Wingate-based HIT protocol, based on Barnett et al (2004)'s protocol, that included adequate rest of 1-2 days between sessions, could elicit similar adaptations and improvements to aerobic fitness (Burgomaster et al., 2005). The traditional Wingate-based HIT protocol (Burgomaster et al., 2005; Gibala et al, 2006) comprises of 4-6 x 30-s maximal Wingate sprints against a resistance of 7.5% of the individual's body mass, each followed by 4 min very low resistance cycling rest periods. Performing just 6 sessions of 4-7 sprints (Burgomaster et al., 2005) was associated with significant improvements to aerobic enzyme activity and muscle glycogen content, as well as a notable 100% increase to cycle endurance capacity, despite no significant change in VO_2max . Gibala confirmed these results in a further study comparing the impact of Wingate-based HIT and endurance training which found no significant differences in improvements to muscle oxidative capacity (Gibala et al., 2006). Since then, multiple meta-analyses have found SIE (the now common term for Wingate-based HIT) to be as effective, if not more so, than MICE in eliciting improvements to aerobic capacity (Gist et al., 2014; Milanovic et al., 2015).

However, despite the success of Wingate-based HIT/SIE in improving physical health, it is challenging to implement within the general population due to the expensive specialised equipment required to perform the Wingate sprints and the strenuous efforts required (Little et al., 2010). This led to the development of interval training protocols that did not involve supramaximal intensities but were still within the 'vigorous intensity' domain that could be conducted without the need for specialised equipment (Little et al., 2010). By matching the maximal aerobic power of active males with their MPO during Gibala and his team's

Wingate trials (Burgomaster et al., 2005; Gibala et al., 2006), Little et al (2010) halved the intensity of the Wingate sprint but doubled the duration of each bout to match the work done (60 s at 100% of the watts (W) at VO_2max). As admitted by Little, the duration/intensity relationship is not linear (Dudley et al., 1982) and thus Little and their team also doubled the number of exercise bouts from 4-6 sprints to 8-12 sprints, with 75 s recovery time between exertions at an intensity of 30 W. Little and his team then minorly adapted this protocol to what will be referred to as ‘traditional HIIE’. This protocol consisted of 10 x 60 s cycling intervals at ~90% of the individual’s maximal HR interspersed with 60 s recovery periods, either rested or cycling slowly against 50 W resistance (Little et al., 2011; Little et al., 2014). A 3 min warm-up and 2 min cool down equalled a total session time commitment of 25 min. The total time commitment per week of traditional HIIE is 75 min for three sessions, identical to the recommended guideline for vigorous intensity exercise, and is half that of the weekly time commitment of MICE. For the purpose of this thesis, while SIE fits within the umbrella term of HIIE, SIE refers to supramaximal exercise, with relatively long (~4 min) rest periods, and HIIE refers to submaximal intensity exercise that is still vigorous-intensity domain, with an elevated HR of above 70% of HR max during the high-intensity exercise bouts (Macintosh et al., 2021).

1.4: Physiological effects of HIIE and SIE

Intramuscular adaptations to SIE are well evidenced. Multiple studies concluded that 30 s Wingate sprints significantly reduced glycogen levels in the muscle which were hypothesised to regulate insulin sensitivity (Babraj et al., 2009; Whyte et al., 2010; Whyte et al., 2013). It has been shown that muscle glycogen levels reduce by 20-30% in the vastus lateralis following repeated Wingate sprints (Esbjornsson-Liljedahl et al., 1999; Parolin et al., 1999; Esbjornsson-Liljedahl et al., 2002; Gibala et al., 2009). However, glycogenolysis was predominantly activated in the first 15 s of the sprint before being greatly reduced in the final 15 s of a 30 s Wingate sprint (Parolin et al., 1999). It was also observed that glycogenolysis activation was attenuated in subsequent repeated sprints (Parolin et al., 1999). Increases in hexokinase and

phosphofructokinase activity increase the rate of glycolysis (Linossier et al., 1997) and reductions in muscle glycogen content and lactate production have been hypothesised to improve insulin sensitivity and glycaemic control (Gibala, 2007). Acute bouts of HIIE and SIE have been found to initiate signalling pathways linked with mitochondrial biogenesis, such as the phosphorylation of signalling proteins such as adenosine monophosphate-activated protein kinase (AMPK) and p38 mitogen activated protein kinase (MAPK), as well as the expression of peroxisome proliferator-activated receptor- γ coactivator 1- α (PGC-1 α), a protein that is theorised to regulate gene expression, cell metabolism, and antioxidant levels (Gibala et al., 2009; Gibala et al., 2012; Little et al., 2011; Metcalfe et al., 2015). The overall effect is an improvement in the efficiency of mitochondrial biogenesis, as well as glucose and fatty acid oxidation capacity (Gibala et al., 2009). Regular activation of these pathways leads to increased mitochondrial density (Coffey and Hawley, 2007). It has been shown that the well-evidenced increase in PGC 1 α , as well as the rate of glycogen utilisation during exercise is due to the increased exercise intensity, when comparing exercise at intensities of 40% and 80% of VO₂max (Egan et al., 2010). AMPK and calcium-dependent protein kinase II only improved in the higher intensity group, but MAPK improved in both (Egan et al., 2010). The increased intensity compared to MICE during acute bouts is also linked to greater adenosine triphosphate turnover (Howlett et al., 1998), potentially due to increased carbohydrate oxidation and glycogen usage (Romijn et al., 1993; Van Loon et al., 2001), increases in lactate accumulation, creatine, adenosine diphosphate, adenosine monophosphate (Howlett et al., 1998; Van Loon et al., 2001), AMPK activity (Egan et al., 2010), and calmodulin-dependent protein kinase II (another signalling protein; Rose et al., 2006; Egan et al., 2010). Di Donato et al (2014) also showed a greater rate of mitochondrial protein synthesis during higher intensity exercise than lower intensity (work matched to lower intensity). Interpretation of physiological adaptations is complicated by substantial variability in protocol design, including sprint duration, recovery length, training frequency, and total intervention duration, all of which have been shown to influence the magnitude of training responses (MacInnis and Gibala, 2017).

Training studies (typically 2-6 weeks) researching HIIE typically assess mitochondrial content via the activity or content of mitochondrial enzymes (e.g. CS and various dehydrogenase enzymes; MacInnis and Gibala, 2017). Improved CS activity is a biomarker for mitochondrial density in skeletal muscle (Leek et al., 2001). Increases in activity of dehydrogenase enzymes, such as succinate dehydrogenase, which catalyses the oxidation of succinate into fumarate in the Krebs cycle (Chilibeck et al., 1998; Chilibeck et al., 1998), and malate dehydrogenase, which catalyses the interconversion of malate and oxaloacetate in the Krebs cycle (Takahashi-Iniguez et al., 2016), both improve the efficiency of the aerobic energy system. CS content and activity is shown to increase at a steady rate over multiple sessions, increasing significantly from baseline after three HIIE sessions (Perry et al., 2010). Mitochondrial content has been shown to increase by roughly 25-35% in both HIIE and SIE after 6 or more sessions (Burgomaster et al., 2006; Gibala et al., 2006; Talanian et al., 2006; MacInnis et al., 2017). A study by Cochran et al (2014) found that maximal CS activity was unchanged following a single 4 min ‘all-out’ bout of cycling 3x a week for 6 weeks, yet it increased during four 30 s ‘all-out’ sprints with adequate recovery periods (SIE). Multiple studies comparing the effect of low-volume SIE protocols and MICE protocols on mitochondrial content found no significant difference in increases after 2, 6, and 12 weeks of training (Gibala et al., 2006; Burgomaster et al., 2008; Gillen et al., 2016), with Gillen et al (2016) showing that 3 x 20 s sprints in a 10 min protocol showed the same increases in maximal CS activity as 150 min of MICE.

HIIE and SIE have also been shown to give central physiological adaptations (MacInnis and Gibala, 2017). A study by Mandic et al (2022) found that a 3 x 30 s sprint protocol thrice weekly increases maximal oxygen uptake (Mandic et al., 2023; Eriksson et al., 2024), plasma volume, blood volume (Mandic et al., 2023; Eriksson et al., 2024), total haemoglobin mass, and cardiac output (Mandic et al., 2023) in a 6-week training block in healthy adults, though a meta-analysis conducted by Astorino et al (2022) found negligible impact of SIE interventions on blood volume or plasma volume. Various studies have corroborated that SIE elicits significant increases to stroke volume, but typically only in longer training protocols of >6 weeks (Matsuo et al., 2014; Astorino et al., 2016; Astorino et al., 2017; Astorino et al., 2018; Raleigh et al., 2018; Zhang

et al., 2019; Astorino et al., 2022), though Trilk et al (2011) found significant improvements to stroke volume after a 4-week SIE intervention in overweight/obese women. MacPherson et al (2011) found that SIE improved VO_2max to a similar extent to MICE but only MICE improved cardiac output after 6 weeks, leading to their hypothesis that adaptations with MICE are primarily central and adaptations elicited by SIE are peripheral, though much of the literature suggests SIE improves both systems (Daussin et al., 2007). This hypothesis is heavily disputed. A review article by Bassett and Howley (2000) suggested that oxygen delivery is the key limiting factor that dictates VO_2max for three reasons; 1) deliberately altering oxygen delivery (through beta-blockers or other doping methods) changes VO_2max . 2) improvements in VO_2max through training are typically through improvements to cardiac output instead of arteriovenous oxygen difference (the difference between arterial blood and mixed-venous blood) and 3) small muscles that are fatigued through exercise have a higher capacity for oxygen uptake than the oxygen the central system can deliver. The muscles can still use more oxygen than is delivered to them at VO_2max . Bassett and Howley (2000) suggested that peripheral adaptations to exercise (such as improvements to mitochondrial density) are crucial for improvements to submaximal performance as this delays the onset of anaerobic metabolism. Astorino et al (2017) agree with this, suggesting that the improvements in VO_2max with various HIIE protocols were due to improvements in oxygen delivery, with a focus on stroke volume. As stated though, most studies only find improvements to cardiac output in longer-term trials and VO_2max has been shown to improve after a SIE intervention of only 2 weeks (Whyte et al., 2010). Thus, it is currently unclear what the exact mechanisms for the increase in VO_2max are, with Raleigh et al (2018) suggesting individual variability in the response to HIIE and that the mechanisms for why this are unknown. Evidence supports SIE and HIIE as effective training protocols for improving a variety of peripheral and central physiological adaptations.

1.5: REHIT

The total time commitment of the traditional SIE and HIIIE protocols does not provide a meaningful advantage over MICE. The ‘traditional HIIIE’ protocol (Little et al., 2011) lasts 25 min with warm-up and cool-down, totalling 75 min a week (3 sessions), and the ‘traditional’ SIE protocol (Burgomaster et al., 2005; Gibala et al., 2006) lasts 22-31 min with warm-up and cool-down applied, totalling 66-93 min a week (3 sessions). Both protocols do not provide a meaningful time advantage over the recommended 75 min of vigorous exercise per week. The idea that fewer sprints can achieve the same goal of improving key health markers is not new. The previously mentioned attenuation of glycogenolysis during repeated sprints (Parolin et al., 1999) and Allemeier et al (1994)’s findings that sessions with three repeated sprints reported a 14% increase in $VO_2\text{max}$, similar when compared to studies using 4 or more sprints reporting 7-15% increases in $VO_2\text{max}$ (Katz et al., 1984; McKenna et al., 1997; MacDougall et al., 1998; Harmer et al., 2000; Barnett et al., 2004), which suggests that doing more Wingate sprints did not necessarily give more benefits. Therefore, the time-commitment issue led to the development of reduced-exertion high-intensity training (REHIT; Metcalfe et al., 2012). Metcalfe et al (2012) created a SIE protocol with a reduced sprint duration, reducing the maximal Wingate sprints from 30 s to 20 s for each sprint, and reducing the total number of sprint repetitions to 2, to create a 2 x 20 s sprint protocol within a 10 min true time commitment, based on the findings of Parolin et al (1999). The remainder of the time in the session is low-intensity warm-up or active recovery. The result of Metcalfe et al (2012)’s protocol was a 28% increase to insulin sensitivity in males, though it did not increase in female participants, with improvements to $VO_2\text{max}$ of 15% and 12% in males and females respectively. A later study found that there was no significant difference between males and females in the change in either glycaemic control or aerobic capacity (Metcalfe et al., 2016). REHIT was associated with a significant reduction in blood glucose levels, increased acetyl-CoA carboxylase phosphorylation, and increased activation of PGC 1 α , all of which (except for PGC 1 α) improve an individual’s anaerobic capacity (Metcalfe and Vollaard, 2024). Cuddy et al (2019) found that over an 8-week training block, REHIT was found to significantly increase $VO_2\text{max}$ both from baseline and

when compared to MICE (REHIT, $3.1 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, 12%; MICE, $1.8 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, 7%). Comparatively, a meta-analysis comparing the aerobic capacity improvements of HIIE and MICE in adult cardiac patients found HIIE improved VO_2 max scores by $1.76 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Xie et al., 2017). Gist et al (2014) found that SIE improved VO_2 max by a mean $3.6 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which was found to have no significant difference when compared to MICE protocols in the studies. These findings show that REHIT achieves the same key outcome, improves cardiorespiratory fitness at an at least as good, if not better, rate. REHIT maintains similar central physiological adaptations to cardiometabolic fitness in comparison to the recommended volume of MICE (Vollaard et al., 2017; Naçakan et al., 2018; Thomas et al., 2020; Hutchinson et al., 2025, under review), as well as blood pressure (Ruffino et al., 2017). Glycaemic control and insulin sensitivity are also found to have similar responses as with MICE (Metcalf et al., 2012; Metcalf et al., 2018), though great inter-individual variability was found for both aerobic capacity and insulin sensitivity (Metcalf et al., 2016).

REHIT also led to improved cardio metabolic risk measurements compared to MICE (Cuddy et al., 2019). In a similar protocol, Gillen et al (2016) found that 3 x 20 s sprints in <10 min total time commitment elicited the same improvements to peak oxygen uptake after a 12-week training intervention in both the 3 x 20 s REHIT and a 50 min MICE session, despite a five-fold reduction in exercise volume and time commitment. Aerobic capacity was improved similarly to what is shown in SIE with a 53% increase to CS, and a 48% increase to CS activity, improving mitochondrial density (Gillen et al., 2016). The study by Gillen et al (2016) also reported that 3- β -hydroxyacyl CoA dehydrogenase (β -HAD), a mitochondrial enzyme responsible for β -oxidation of fatty acids, increased by 28% in SIE, further evidencing aerobic metabolism improvements. Low-volume SIE has been shown to promote increased calcium concentration within skeletal muscle cells, another signal for mitochondrial biogenesis, as well as a reduction in aconitase (an enzyme that catalyses citrate into isocitrate) activity in the TCA cycle and increased citrate concentration, hypothesised to inhibit mitochondrial damage (Macinnes and Gibala, 2017). Data reported by Granata et al (2015) showed that there was no significant difference in increases to lactate threshold

(LT) during low-volume SIE when compared to higher-volume HIIE and MICE. Similarly, the study conducted by Thomas et al (2020) found there to be no significant difference in changes to maximal aerobic capacity in either 2, 3, or 4 sessions of REHIT each week (6-week training block), aligning with the recurring theme with SIE that doing more does not produce greater results. This has been confirmed in a recent meta-analysis that found no significant difference in improvements to absolute $\text{VO}_{2\text{max}}$ when increasing the number of sprints in a session, or the duration of those sprints (Hutchinson et al., 2025, under review). REHIT has a total exercise volume per week of 20 minutes, compared to the currently recommended 75 minutes of vigorous intensity exercise (Metcalf et al., 2020), while maintaining similar key health benefits as the recommended 150 min MICE (Gillen et al., 2016; Ruffino et al., 2017; Cuddy et al., 2019; Thomas et al., 2020). Therefore, REHIT may offer a more appealing and efficient exercise protocol from a time perspective (Cuddy et al., 2019; Metcalf et al., 2020) and could effectively nullify the time-commitment issue for many of the general population.

1.6: Affective valence (AV)

Despite the fact that the classic HIIE and SIE protocols are less time-efficient than previously claimed, there have been additional strong criticisms of the use of HIIE and SIE training protocols in the sedentary and inactive populations (Hardcastle et al., 2014; Biddle & Batterham, 2015; Ekkekakis & Biddle, 2023; Ekkekakis et al., 2023c; Ekkekakis & Tiller, 2022; Ekkekakis et al., 2023d; Ekkekakis et al., 2023a; Ekkekakis et al., 2023b). In order to ease confusion with references, Ekkekakis et al (2023a) refers to ‘a methodological checklist for studies...’ part 1, and Ekkekakis et al (2023b) refers to ‘a methodological checklist for studies...’ part 2. Ekkekakis et al (2023c) refers to ‘extraordinary claims in the literature...’ part I, and Ekkekakis et al (2023d) refers to ‘extraordinary claims in the literature...’ part III. Due to the supramaximal intensity of SIE sprints and the vigorous intensity of HIIE bouts, it has been argued that these protocols will be experienced as unpleasant by inactive populations (Hardcastle et al., 2014; Biddle &

Batterham, 2015; Ekkekakis & Biddle, 2023; Ekkekakis et al., 2023c; Ekkekakis & Tiller, 2022; Ekkekakis et al., 2023d; Ekkekakis et al., 2023a, Ekkekakis et al., 2023b). Feelings of pleasure or displeasure during exercise are known as an individual's AV. AV can be described as how one feels in a given moment during a stimulus ranging from most pleasant to least pleasant, with positive AV reflecting a pleasant experience and negative AV reflecting an unpleasant experience. In-task AV responses during exercise are typically measured using the feeling scale (FS; Hardy and Rejeski, 1989). The FS is an eleven-point scale where 5 means you feel 'very good' and -5 means you feel 'very bad', with 0 as a neutral point. This quantitative scale allows for data to be collected at regular time intervals and is feasible to use during exercise bouts as participants just need to either point at, or say, a number for their response. The majority of studies within the field report AV as a mean value across time points during exercise (Zenko et al., 2016; Decker and Ekkekakis, 2017; Songsorn et al., 2020). This allows for pre-task and post-task data measurements that highlight the AV response during exercise and once the exercise bout has been completed. This means deviations from 'baseline' or 'normal state' AV during exercise can be compared across multiple exercise protocols.

It has been shown that individuals experience a sharper 'drop' (i.e. going from feelings of positive AV to potential negative (or just less positive) AV in a short duration) in AV during HIIE and SIE (Niven et al., 2021) and that AV responses during SIE are increasingly negative with each additional repeated sprint (Metcalf et al., 2022). Hardcastle et al (2014) suggested that the negative AV responses will lead to a lack of enjoyment. As enjoyment is a hypothesised predictor of exercise adherence (Parfitt and Hughes, 2009), Hardcastle et al (2014) hypothesised poor SIE adherence levels in sedentary populations. AV during exercise can be modified, inducing feelings of positive AV, feelings of negative AV, or a neutral response to the exercise stimulus (Ekkekakis et al., 2008). Changes in an individual's AV during exercise are hypothesised to impact the uptake and long-term adherence of exercise (Lacharité-Lemieux et al., 2015; Williams et al., 2016; Bock et al., 2021), as positive AV during exercise has been linked to increased exercise enjoyment (Raedeke, 2007) which may be a key factor impacting upon exercise adherence.

Therefore, understanding what causes an individual's AV to change is extremely important for the health of the general population.

Early research into the subject produced the idea that exercise leads to a universal improvement in affect via a decrease in stress, depressive state, and increases in perceived energy levels (Lawrence, 1983; McCann and Holmes, 1984; Dishman, 1985; Biddle et al., 2000; Berger and Motl, 2000), with W. P. Morgan concluding his decades of research by stating that PA results in improved mood (Morgan, 1997). Studies from this period typically only measured AV pre and post exercise (Morgan et al., 1971; Hatfield et al., 1987; Isen et al., 1987), which, as more recent studies have shown, is an ineffective way of measuring AV as most individuals report a post-exercise increase in affect to return to, or rise above, baseline levels, despite typically decreasing during exercise (Oliveira et al., 2013; Decker and Ekkekakis, 2017; Schutte et al., 2017; Songsorn et al., 2020). Research in the late 1980s and into the 1990s began to focus on in-task affect, with a multitude of protocols showing varying AV responses to tasks, some positive, but the majority negative (Hardy and Rejeski, 1989; Parfitt and Eston, 1995; Boutcher et al., 1997). In the early 2000s The Dual Mode Model (DMM; Ekkekakis et al., 2020) was developed, stating that the intensity at which an individual was working at during exercise was the key to determining one's AV responses during exercise, with the ventilatory threshold (VT) theorised as being the key physiological turning point that impacts AV (Ekkekakis, 2003; Ekkekakis et al., 2005; Ekkekakis et al., 2008; Ekkekakis, 2009; Ekkekakis et al., 2020). The VT can be described as the point in an individual's breathing where ventilation increases due to the buffering of metabolic CO₂ (Wasserman et al., 1973; Gaskill et al., 2001; Poole et al., 2021). During exercise at intensities above the VT, blood pH drops due to lactic acidosis and so the physiological response to this is to increase ventilation. This causes an increase in the carbon dioxide exhaled, restoring the blood pH to a point of homeostasis (Wasserman et al., 2014).

Ekkekakis developed the DMM (**Figure 1.**) based on the hypothesis that the VT is a definitive physiological turning point for AV responses. According to the theory, an individual's affective response to exercise is influenced simultaneously by cognitive factors (such as physical self-efficacy or goals), and interoceptive

factors (such as respiratory or muscular cues), leading to pleasure or displeasure while exercising (Ekkekakis, 2003; Ekkekakis and Acevedo, 2006; Ekkekakis, 2009). The theory describes three physiological domains; moderate, heavy, and severe. The moderate intensity domain encompasses exercise up to the point of the VT and is hypothesised to produce a homogenous positive response (increases in pleasure) in all individuals, with the exception of obese individuals. The heavy intensity domain regards exercise at intensities between the VT and the respiratory compensation point (RCP; the onset of hyperventilation during exercise (Keir et al., 2024)). This zone is hypothesised to produce a heterogenous AV response where some individuals will feel increased feelings of pleasure, some will not change, and some will feel more feelings of displeasure. The final domain is the severe intensity domain which involves all exercise at intensities greater than the RCP. This domain is hypothesised to produce a homogenous negative AV response; all individuals will exhibit feelings of displeasure during any exercise at these intensities. These hypothesised zones of AV responses align with the hedonic theory (Cabanac, 1992; Williams, 2008), the idea that all human behaviour is driven by the evasion of pain, or general displeasure, and the pursuit of pleasure. The balance between the cognitive and interoceptive factors is hypothesised to work as a system around exercise intensity, with cognitive factors being dominant at lower intensities, shifting to interoceptive factors as exercise intensity increases and the individual is unable to maintain a physiological steady state. This suggests that up to the VT (lower intensity) an individual would find exercise to be manageable, leading to positive affective responses, and exercise above the VT would be perceived as less manageable and affective responses will be increasingly negative as the individual's physiological state deteriorates (Ekkekakis, 2003; Ekkekakis and Acevedo, 2006).

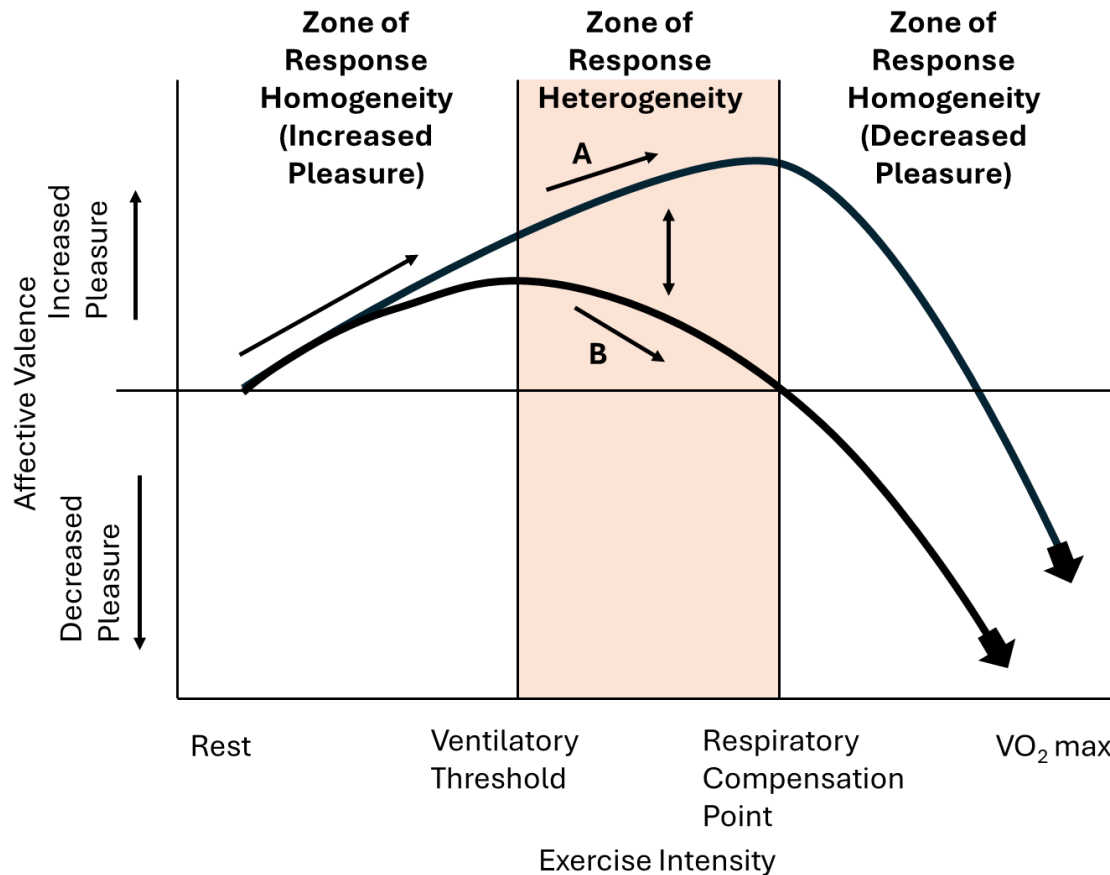


Figure 1. The Dual Mode Model. Adapted from Ekkekakis (2013), Routledge Handbook of Physical Activity and Mental Health. Used for academic purposes.

The intensities reached during SIE far exceed what is given on the X-axis of Figure 1. During supramaximal exercise the peak intensity was found to be 2.7 times greater than maximal aerobic power at VO₂max in junior elite cyclists (Stoa et al., 2024), with studies reporting the PPO during REHIT in individuals with type-2 diabetes to be 2-4-fold greater than the power elicited at VO₂max (Ruffino et al., 2017; Metcalfe et al., 2018; Metcalfe and Vollaard, 2024). In a ‘real-world’ office setting, Metcalfe et al (2020) found unsupervised participants still achieved a 2.8-fold greater power output during the REHIT sprints compared to the power elicited at VO₂max. According to the DMM, this would imply every single individual who takes part in a SIE session or exercise bout should feel a decrease in pleasure and thus this type of exercise should not be recommended for inactive populations because it is unlikely to be adhered to (Hardcastle et

al., 2014; Biddle & Batterham, 2015; Ekkekakis et al., 2020). If this is the case, as these criticisms state, then the intensity of HIIE and SIE bouts is far too strenuous for sedentary and inactive populations to endure. The intensity of the exercise is hypothesised to reduce in-task AV (Ekkekakis et al., 2008; Ekkekakis, 2009; Ekkekakis et al., 2020). Decreased AV during exercise is linked to reduced remembered exercise enjoyment (Raedeke, 2007). Lower remembered exercise enjoyment levels are linked to reduced uptake of and adherence to exercise (Jekauc, 2015). This hypothesised pathway would render HIIE and SIE not suitable as exercise protocols according to the DMM (Ekkekakis et al., 2020). In a recent meta-analysis, Metcalfe et al (2022) found that AV during exercise significantly decreased during each additional repeated sprint, and that the duration of each sprint also had a significant negative effect on AV during exercise. While this confirms that SIE with several repeated supramaximal sprints will lead to increasingly greater drops in AV, it also suggests that the drop in AV may be attenuated in low-volume SIE protocols. This is supported by studies demonstrating that due to the low number of sprints, and reduced duration compared to classic SIE, the drop in AV associated with REHIT appears to be manageable (Songsorn et al., 2020).

1.7: Duration and Enjoyment

A recently published checklist for research into AV suggested that all MICE protocols should consist of sessions lasting between 30-45 min (Ekkekakis et al., 2023b) to ensure a fair comparison between difference exercise types. However, the DMM (Ekkekakis, 2009) was based on seminal data where participants performed MICE sessions lasting just 15 min (Ekkekakis et al., 2008), with several other studies also analysing bouts of 15 min or less (Tempest and Parfitt, 2013; Bird et al., 2019; Jones and Ekkekakis, 2019). Comparisons between exercise modalities are often confounded by differences in total work, duration, and intensity prescription, making it difficult to isolate whether affective responses are driven by modality itself or by mismatched protocol characteristics, and thus hard fast conclusions, such as the framework for the DMM (Ekkekakis et al., 2020) should not have been drawn until studies that were able to eliminate or

justify the difference could be completed. A study by Songsorn et al (2020) found that in a MICE session lasting 30 min at 50% of the maximum W during VO_{2max} (for reference, 100% of VT is estimated to be between 50 and 60% of VO_{2max} for low active individuals; Anselmi et al., 2021), there was a steady decrease in AV, dropping significantly compared to baseline after the 15 min mark. This is a typical trend with AV responses to MICE, a gradual decline in AV as the exercise bout progresses (Ekkekakis et al., 2008; Decker and Ekkekakis, 2017; Songsorn et al., 2020), very different to the typical responses to low volume SIE where AV steeply drops during the sprint then returning to near, but always increasingly lower with each sprint, baseline levels during the rest periods before steeply dropping, again increasingly lower each time, during the following sprints (Songsorn et al., 2020).. Therefore, while AV is expected to decrease more quickly during REHIT than in MICE (Songsorn et al., 2020), the short duration of high-intensity bouts may limit both the drop in AV and the duration of time spent in a negative affective state. During MICE the drop is expected to decrease more slowly (Ekkekakis et al., 2008; Songsorn et al., 2020), but the gradual reduction over a longer period may lead to a greater duration spent at a negative affective state. Until the study conducted by Songsorn et al (2020), no study had compared the decrease in AV responses in commonly used durations of MICE (30 mins) to commonly used supramaximal SIT durations (20-30 seconds), meaning that the criticisms proposed by authors in the field (Hardcastle et al., 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2020) have not been confirmed with evidence. Songsorn et al (2020), found some evidence to suggest that, during supramaximal exercise, AV will not drop to lower levels than MICE. Focusing on the drop in affect as a fluid concept over time as opposed to stating that the condition with the lowest point of FS data is the 'least pleasant' could explain the results of two recent meta-analyses (Oliveira et al., 2018; Niven et al., 2021) that found HIIE to be associated with greater enjoyment levels than MICE, despite the typically greater drop in AV.

1.8: Interindividual Variability in AV Responses

The results from the Songsorn et al (2020) study also suggested a heterogenous response to REHIT between participants. A relatively large standard deviation (SD; 3.0) showed that some participants had a positive

AV response to REHIT, some had a neutral AV response, some had a small negative AV response, and some had a large negative AV response, with the mean being small a negative response (-2.7 FS units). Variability in individual responses may be used to identify potential factors that moderate changes in AV during exercise, offering the potential to predict individual trajectories of AV response. Previous research into this topic has led to theories of various predictors of affective responses to exercise. Firstly, an individual's perceived competence of the upcoming exercise and their previous exercise experience (Ekkekakis et al., 2011). An individual's perception of their competence in exercise is often derived from past experiences (Rose and Parfitt, 2012; Williams et al., 2018; Calder et al., 2020). Those with positive expectations are shown to have greater exercise enjoyment, improved general mood state, and a reduction in anxiety (Rose and Parfitt, 2012; Mothes et al., 2017), though Raedeke et al (2009) found that experience only had an impact on self-efficacy and did not impact enjoyment among women with high social-physique anxiety. Secondly, an individual's anatomical autonomy (Rose and Parfitt, 2012). Anatomical autonomy refers to an individual's belief in their own ability and control over the choices that they make (Moustaka et al., 2012). Positive autonomy is linked to increased enjoyment and increased positive affect during exercise, with reduced perceived autonomy linked with decreases in AV (Puente and Anshel, 2010). Thirdly, an individual's perception of their body fat (Ekkekakis and Lind, 2006). An individual's perception of their own body fat has been shown to have an impact on exercise enjoyment and self-esteem (Guinn et al., 1997), and that improved perception of an individual's body image and body fat percentage may lead to increased exercise adherence in school children (Morano et al., 2020). Lastly, Pavey et al (2012) have also found gender and age to impact exercise enjoyment. Individuals under 24 years of age are shown to have typically reduced exercise enjoyment and perceived motor competency, with perceived motor competency increasing with age before decreasing from around age 45 and decreasing more rapidly from age 60 (Kakebeeke et al., 2023). A meta-analysis conducted by Alcaraz-Ibanez et al (2022), found females to have small-to-moderate increases in exercise withdrawal and lack of exercise enjoyment, when compared with males.

Felt arousal (FA), as measured using the FA scale (Svebak and Murgatroyd, 1985), refers to the perceived activation or emotional response experienced by an individual during an exercise session. FA (sometimes referred to as activation but for the purposes of this thesis shall be referred to as FA) is proposed to interact with AV during exercise to elicit an expended affective response to the stimuli (Bastos et al., 2023). The FA scale is a neutral scale in the sense that high arousal could simultaneously denote excitement, anxiety, high-energy, or anger. In order to differentiate between these very different human emotions, a circumplex model was proposed, with four quadrants in a circumplex model (Russell, 1980; Ekkekakis, 2008). The four quadrants consist of: 'high-activation pleasure' displayed as excitement, high-energy, and enthusiasm, 'high-activation displeasure' displayed as anger, tension, and distress, 'low-activation pleasure' displayed as calmness, tranquillity, and relaxation, and finally 'low-activation displeasure' displayed as depression, low-energy, and boredom (Russell, 1980; Ekkekakis, 2008). The interaction between FA and AV as independent variables, rather than combining the two, has not been explored in exercise. The circumplex model can display whether an individual is in a state of calmness or tension combined with a state of pleasure or displeasure (Evmenenko and Teixeira, 2022), but it does not explore, for example, whether FA increases as AV decreases or any other interaction effect. There is also a lack of literature on the physiological response to an increase in FA, or vice versa if an increase in FA is a response to a change in physiological state. Despite being included in the affective response 'umbrella' with AV, FA has not been researched as extensively on its own (Bastos et al., 2023). Other psychological traits have been hypothesised. Tabor et al (2019) found that an individual's anxiety sensitivity index has been suggested to impact SIE performance. Anxiety is an emotion that can be characterised by apprehension about a real or perceived future event in which somatic symptoms of tension are activated, including physical symptoms such as reduced heart rate variability (HRV; Licht et al., 2009; Chalmers et al., 2014). High levels of anxiety are associated with higher perceived stress, lower resilience, and lower life satisfaction (Miron et al., 2019). High levels of anxiety are also linked to an increased risk of cardiovascular problems (Emdin et al., 2016), and reduced PI levels, increased smoking prevalence, and increased BMI in young adults (Patterson et al., 2022). Tabor et al (2019) found that greater interoceptive accuracy and increased anxiety levels had a

negative impact on power output during repeated sprint tasks, with reduced performance during exercise linked with decreased remembered exercise enjoyment (Box et al., 2023). A link was also found between anxiety and body perception by Tabor. Body perception can be described as an individual's awareness of, interpretation, and evaluation, of the physiological sensations within their body (Porges, 2022).

Physiological factors that may influence AV change have also been suggested. Aligning with the DMM, Ekkekakis and team have hypothesised that during exercise bouts of vigorous intensities, the deoxygenation of the pre-frontal cortex (PFC) associated with exercise will occur to a greater extent than during exercise bouts at moderate intensities, specifically below the VT (Ekkekakis, 2009). The PFC is the region of the brain responsible for cognitive control functions, such as attention, impulse inhibition, prospective memory, and cognitive flexibility, moderated by dopamine levels (De Wachter et al., 2021; Friedman and Robbins, 2021). Inhibition of these functions can lead to non-typical emotional and behavioural responses (Narayanan and Laubach, 2017). Increased intensity above the anaerobic threshold induces physiological responses, such as increased sympathetic activity and an elevation of blood catecholamine levels; raising HR, blood pressure, and ventilation rate (Sales et al., 2019). Robertson and Marino (2015) found a significant increase in electroencephalography (EEG) activity during incremental exercise from 50% of VO_2 peak to the RCP, before EEG activity decreased between RCP and volitional exhaustion. At levels around 70-80% of $\text{VO}_{2\text{max}}$ the oxygen usage rate outweighs the oxygen intake and thus leads to muscle acidosis and a loss of contraction function (Osawa et al., 2011; Racinais et al., 2014). This usage in the muscle leads to deoxygenation of the PFC and cerebral hypoperfusion through increased vasoconstriction of cerebrovascular arteries (Yang et al., 2015) and the reduced cerebral oxygenated blood flow impacts motor planning and command (Subudhi et al., 2009; Vasconcelos et al., 2019). It is proposed that the reduced PFC oxygen levels are linked to negative impacts on AV and changes in participants' emotional behaviour (Ladwig et al., 2017; Da Silva et al., 2017), but as of now there is yet to be a study conducted to confirm this. It is possible that the short duration of sprints during SIE that are thought to attenuate the feelings of displeasure during exercise could also attenuate the deoxygenation of the PFC compared to

MICE. In REHIT sprints of only 20 seconds, it is unknown whether this would be sufficient time for this process to occur.

Blood lactate concentration ([La-]b) during exercise have also been proposed to influence AV change. In a review, Astorino and Vella (2018) found that in trials that recorded AV levels, RPE levels, and [La-]b levels, 62% of the change in AV during exercise could be elucidated by a combination of the baseline AV score, [La-]b levels, and the remembered exercise enjoyment scores, leading to the hypothesis that pre-exercise AV scores and [La-]b could predict AV change during exercise. Another hypothesised physiological predictor of AV change score is HRV. Borchardt et al (2018) found a negative association with non-exercise AV and HRV and mood score. This finding could potentially be transferable to an exercise setting, with HRV linked to anxiety levels as previously mentioned (Licht et al., 2009; Chalmers et al., 2014), with reduced HRV linked to reduced exercise performance from resistance training to cardiovascular training (Young and Benton, 1993; Araujo et al., 2014; Panissa et al., 2016; Amekran et al., 2024), though Kingsley and Figueroa (2016) found that resistance training did not modify resting HRV in healthy young adults.

1.9: Limitations Within the Existing Literature

There is considerable evidence that the global PI pandemic is continuing to worsen, at great expense to mortality rates and the global economy, with the uptake and adherence of currently recommended modes of exercise proving to be ineffective at solving this crisis. This review of the available literature has outlined the effectiveness of low-volume SIE protocols as a method of improving aerobic fitness, but the efficacy of these protocols as interventions for the sedentary and inactive populations has been heavily criticised by authors within the field of exercise psychology, leaving (as of yet) unanswered questions on the topic of AV responses during exercise. As stated previously, there is a body of evidence that contradicts the hypothesis stated within the DMM (Ekkekakis, 2009; Ekkekakis et al., 2020) that all exercise bouts performed at intensities below the onset of the VT will elicit a homogenous increase in pleasure. For the

DMM hypothesis to be accepted, it must be shown that no trials involving MICE interventions report a decrease in AV during exercise. If this is not the case, then the DMM's hypothesis that exercise at intensities above the RCP (into the severe domain) will elicit a homogenous decrease in pleasure can also be disputed. If this is the case, then the stated advantage of MICE protocols as exercise interventions for sedentary and inactive populations is not an advantage, allowing for investigations into the usage of SIE interventions in sedentary and inactive populations as they may be more feasible than originally thought, if the drop in AV with sit can be kept manageable. Metcalfe et al (2022) showed that AV responses to SIE are dependent on the duration of each repeated sprint, as well as the number of sprint repetitions, with Songsorn et al (2020) showing no significant difference in AV responses during exercise between REHIT and MICE. It needs to be shown that the similarities in AV responses between REHIT and MICE translate to similar remembered exercise enjoyment levels as the findings by Raedeke (2007) hypothesise, as well as showing that significant differences in AV responses, such as REHIT and classic SIE, elicit significant differences in remembered exercise enjoyment. Confirming this link would allow for an argument that low-volume SIE protocols are feasible interventions for sedentary and inactive populations in terms of uptake levels and long-term exercise adherence, as Jekauc (2015) hypothesised. The variability reported between participants during REHIT (Songsorn et al., 2020) suggests that individuals will have differing AV responses to exercise with some reporting increasing pleasure, and some reporting large decreases in pleasure. Confirmation of this finding would suggest the existence of a factor (or factors) that could determine the response of each individual for an exercise mode.

1.10: Aims and Objectives

Having discussed the literature on the topic of AV responses to exercise and their potential effect on general public health initiatives and guidelines, the limitations of the existing literature are clear. Thus, the

overarching aim for this thesis is to elucidate what affects AV change during exercise and how that is linked to exercise enjoyment levels.

This aim will be achieved through completing the following objectives:

1. To meta-analyse all available literature to identify whether the hypothesis of the DMM (Ekkekakis et al., 2020) that exercise below the VT elicits a homogenous improvement in AV, exercise at the VT elicits a heterogeneous response, and exercise above the VT elicits a homogenous decrease in AV, can be confirmed.
2. To elucidate whether exercise enjoyment and changes in AV during exercise depend solely on exercise intensity or on exercise duration as well, by comparing exercise bouts of different intensities and durations.
3. To investigate the variability of AV responses to REHIT within and between individuals.
4. To ascertain potential associations between the change in AV with exercise and psychological characteristics.

Chapter 2- Effect of exercise intensity relative to the ventilatory threshold on affective responses during exercise: a systematic review and meta-analysis

2.1: Introduction

The benefits of PA on physiological health are well evidenced (Miller et al., 2016; Ruegsegger and Booth, 2018), with PI being accredited as the primary cause of 35 chronic conditions (Booth et al., 2012; Gillett et al., 2012; Booth et al., 2017). There are a multitude of varying factors that have been attributed to causing PI within the population, such as a lack of time (Trost et al., 2002; Korkiakangas et al., 2009; Louw et al., 2012; Justine et al., 2013), lack of money (Rimmer et al., 2008), low self-efficacy (Blake et al., 2017), fatigue (Ebben and Brudzynski, 2008), and negative affective responses (Haines et al, 2020). An individual's AV, their perceptual feelings of pleasure (positive AV) or displeasure (negative AV), can be impacted upon by exercise (Raedeke, 2007; Ekkekakis et al., 2011). These feelings of pleasure or displeasure are important as they may impact exercise enjoyment (Focht, 2009; Williams et al., 2016). It has been theorised that a decrease in AV while exercising is associated with reduced exercise enjoyment, potentially leading to a lack of uptake and adherence of PA (Williams et al., 2012; Haines et al., 2020). Therefore, negative AV responses to exercise could influence uptake of, and adherence to, exercise (Jekauc, 2015). It is still unclear exactly how exercise impacts AV, and whether exercise protocol parameters may have an impact upon AV, either positively or negatively. Studies have shown a post-exercise bounce in AV to return to, or rise above, pre-exercise levels after typically dropping during exercise (Oliveira et al., 2013; Decker and Ekkekakis, 2017; Schutte et al., 2017; Songsorn et al., 2020).

It is theorised by authors in the field that the VT is a key point during exercise that impacts AV (Ekkekakis, 2000; Hall et al., 2002). The VT is the volume of oxygen (VO_2) uptake immediately below the VO_2 at which pulmonary ventilation increases at a disproportionate rate relative to VO_2 (Reybrouck et al., 1986). The DMM (Ekkekakis, 2003; Ekkekakis, 2009; Ekkekakis et al., 2020) hypothesises that an individual's AV during exercise is influenced simultaneously by cognitive factors, such as physical self-efficacy, and interoceptive factors, such as respiratory or muscular cues, leading to pleasure or displeasure while exercising (Ekkekakis, 2003; Ekkekakis and Acevedo, 2006; Ekkekakis, 2009; Ekkekakis et al., 2020). Cognitive factors are hypothesised to be dominant at lower intensities, shifting to interoceptive factors as exercise intensity increases and the individual is unable to maintain a physiological steady state. The DMM hypothesises that exercise at intensities below the VT will elicit a steady, or increasing, level of pleasure, exercise between the VT and the RCP will elicit a heterogeneous AV response, and exercise above the RCP will elicit a decreasing level of pleasure due to the inability to maintain a steady physiological state, suggesting that exercise above the RCP may lead to reduced function or deregulation occurring in different regions of the PFC (Tempest et al., 2014). Steady states can be achieved at intensities between the VT and the RCP, but this is dependent on the individual, hence the suggestion of a heterogeneous zone response (Wasserman et al., 2012). It is proposed that the reduced PFC oxygen levels are linked to negative impacts on AV and changes in participants' emotional behaviour (Ladwig et al., 2017; Da Silva et al., 2017), but little empirical evidence has been provided to aide, or refute, this theory. The DMM implies that all individuals will increase their pleasure during exercise at intensities below the VT. However, this is not supported by all current literature. Studies researching continuous exercise at intensities below the VT have shown decreases in AV (Oliveira et al., 2013; Songsorn et al., 2020), including Ekkekakis' own data (Decker and Ekkekakis, 2017). Therefore, the aim of the present study is to meta-analyse the available literature to identify whether the hypothesis of the DMM that exercise below the VT elicits a homogenous improvement in AV, exercise at the VT elicits a heterogeneous response, and exercise above the VT elicits a homogenous decrease in AV, can be confirmed.

2.2: Methods

2.2.1: Literature search and study selection

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines 2020 (Page et al., 2021; Figure 1). The objective was to source all studies that have examined changes in AV during continuous exercise with the intensity set relative to the VT or LT. To achieve this, the online databases of PubMed, Web of Science, PsycINFO, and Scopus were searched for available records up to August 1st 2024, using the 4 possible combinations of the independent variable search terms ‘feeling scale’ OR ‘affective valence’ and the dependent variable search terms ‘ventilatory threshold’ OR ‘lactate threshold’. The following articles were excluded: 1) review articles, commentaries, conference abstracts, and case studies, 2) studies with a mean participant age <18 years, 3) animal studies, 4) study populations including patients (any clinical population, such as individuals with type-2 diabetes) or athletes (any individual who performs structured exercise beyond recreational level), 5) articles not in English, 6) studies that did not use the FS (Hardy and Rejeski, 1989) to assess changes in AV, 7) studies that did not use the VT or LT to set exercise intensity, 8) studies that combined exercise with additional interventions that may affect AV, and 9) studies that did not assess AV before and during exercise. After further consideration, only studies that kept the intensity relative to the VT constant were included, self-selected and interval training protocols were excluded. Two authors (DJK and NBJV) independently conducted the literature search, with one author (DJK) performing the data extraction, and any discrepancies were resolved by consensus. After duplicate articles had been removed the titles and abstracts of the remaining articles were screened for studies that were not relevant to the topic. These studies were removed from consideration before the eligibility of the full-text editions of the remaining articles was assessed to decide inclusion to the meta-analysis.

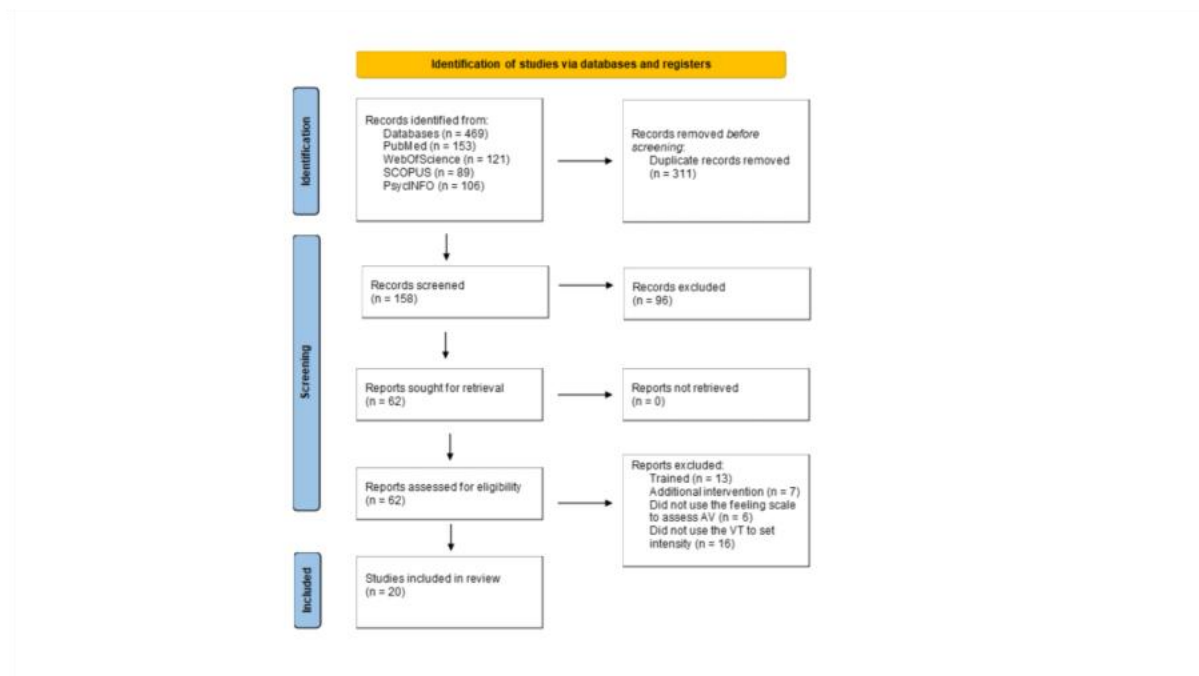


Figure 1. PRISMA flow diagram illustrating the study screening and selection process for this meta-analysis, adapted from Page et al (2021). This work is licensed under CC BY 4.0.

2.2.2: Data Extraction

20 Full papers were assessed for participant characteristics (including age, sex, BMI, duration, and relative VO_2max score), the duration of the exercise protocols used, baseline mean FS data, the intensity that exercise was set to (relative to the % of VT), and the value of the greatest change in AV during exercise from baseline. Data for time points post-exercise were excluded. The corresponding authors of studies without the required data were contacted by email; authors from 17 studies were contacted (Parfitt et al., 2006; Ekkekakis et al., 2008; Hargreaves and Sytch, 2013; Tempest and Parfitt, 2013; Jones et al., 2014;; Tempest and Parfitt, 2016; Decker and Ekkekakis, 2017; Hoekstra et al., 2017; Niven et al., 2018; Bird et al., 2019; Haile et al., 2019; Jones and Ekkekakis, 2019; Zenko and Ekkekakis, 2019; Slawinska and Davis, 2020; Bogdanis et al., 2021; Dierkes et al., 2021; Prado et al., 2021) and raw data were received from 7 of these studies (Hargreaves and Sytch, 2013; Hoekstra et al., 2017; Niven et al., 2018; Bird et al., 2019;

Zenko and Ekkekakis, 2019; Bogdanis, 2021; Prado et al., 2021). Graph digitizer software (DigitizeIt, Braunschweig, Germany) was used to obtain data from five studies for which the mean FS data at each time point were only available in a figure (Ekkekakis et al., 2008; Tempest and Parfitt, 2013; Decker and Ekkekakis, 2017; Jones and Ekkekakis, 2019; Dierkes et al., 2021). All data were recorded as mean values with SD values calculated from exact p-values, except for the intensity relative to the VT which was recorded as a percentage. The following were identified as covariate moderators: percentage of VT, baseline AV, percentage of female participants, BMI, age, and $\text{VO}_{2\text{max}}$. Risk of bias and quality of reporting were assessed using the Cochrane Collaboration Risk of Bias tool (Higgins et al., 2011). Data from Bird et al (2016), Bird et al (2021), and Hutchinson et al (2015) were removed from the final analysis due to not recording baseline FS. The data from Tempest and Parfitt (2013) were also removed from the final analysis due to not recording $\text{VO}_{2\text{max}}$ data. The final dataset included the results of 638 total participants (397 unique) from 27 outcomes from 14 studies. NICR ethical approval was received from the Stirling of University.

2.2.3: Statistical Analysis

The assumption of normal distribution of the data was assessed by plotting the empirical cumulative distribution of the data and of a fitted normal distribution with confirmation by using a quantile-quantile plot (Das and Imon, 2016; although the relatively low number of studies included in this meta-analysis does make this assumption less assured). The relationship between exercise intensity and change in AV was plotted using a Loess smoother (Gijbels and Prosdocimi, 2016) which showed minimal change in AV as exercise increases until the VT, suggesting, as The DMM predicts (Ekkekakis et al., 2008), a non-linear model would fit the data. The key moderators were all centred at their means, aside from exercise intensity (centred at 100%, with 100% stated as '0') and % female (centred at 50%). A collinearity check was performed to check for collinearity between predictor variables.

Bayesian meta-regression was conducted, using the ‘brms’ package in R Studio (Burkner brms package, 2017; R studio version 4.3.1; R Foundation for Statistical Computing, Vienna, Austria), to examine the effects of exercise intensity relative to the VT on AV. A Bayesian approach was selected because it allows estimation of full posterior distributions and probabilistic interpretation of parameter estimates, rather than reliance on dichotomous significance testing inherent in frequentist null-hypothesis testing (Gelman et al., 2013). Bayesian inference has been recommended as a more informative framework, particularly for small samples and complex models, as it quantifies uncertainty directly and reduces overreliance on p-values (Wasserstein et al., 2019). Meta-regression attempts to explain study heterogeneity in terms of study-level variables, summarising information as a function as opposed to a single value (e.g. a mean). The covariates for the function (linear and non-linear model) are the previously stated moderators. Both linear and non-linear modelling was performed. A Pareto smoothed importance sampling leave-one-out (PSIS-LOO) cross validation was used to compare the non-linear model with a linear model (appendix 1), with lower expected log pointwise predictive density leave one out (ELPD-LOO) values representing a better predictive performance. The ELPD-LOO values showed no significant difference in the predictive ability of the linear or non-linear models (linear= -50.49, non-linear= -50.46). As the DMM suggests a non-linear model, and the difference between models falls within the margin of error, the non-linear model was chosen for the analysis (Appendix 2- the linear model; Appendix 3- the linear model waterfall plot; Appendix 4- the linear forest plot). Bayesian analysis requires the specification of priors (Gelman et al., 2008). Weakly informative priors were selected to regularise estimates while minimising undue influence on posterior distributions, which is recommended when prior knowledge is limited (Gelman et al., 2008; Vehtari et al., 2017). A normal prior was set for the intercept with a mean of 2 and a SD of 2, stating a 95% probability of the intercept falling between -2 and 6 in the ‘change in AV from baseline score’, reflecting plausible values without being overly restrictive. A normal distribution with a mean of 0 and an SD of 1, stating a 95% probability of the slope coefficients falling between -2 and 2, was selected for the slope coefficients, constraining moderator effects to realistic ranges while allowing sufficient flexibility (Kruschke, 2014). The prior for the between-study

heterogeneity must be positive and, given the small number of studies, heterogeneity could be substantial; therefore, a half-Cauchy distribution between 0 and 1 was selected, as recommended for variance parameters in hierarchical models by Gelman (2006). The priors for the spline term were restricted cubic splines set between 0 and 2, with three knots as recommended (Harrell, 2015; Harrell and Levy, 2022), allowing flexible modelling of potential non-linear relationships while avoiding overfitting.

A collinearity check showed a strong correlation between BMI and VO_{2max} ($r = -0.75$), but moderate-to-minimal relationships between all other moderators (Figure 2). Although this correlation is relatively high, it did not exceed commonly cited thresholds for problematic multicollinearity ($r > 0.80-0.90$; O'Brien, 2007; Voss et al., 2005), and thus both variables were retained due to their theoretical relevance. Moderators were centred at their means to improve model interpretability and reduce correlation between intercept and slope estimates (Gelman and Hill, 2007). Studies lacking required moderator data were excluded from the meta-regression to ensure consistent model estimation. Non-linear relationships were accommodated using restricted cubic splines, and all moderators were entered simultaneously to estimate independent effects (Harrell, 2015). Ekkekakis et al (2008) reported separate descriptive measurements (age, BMI, and VO_{2max}) for males and females as subgroup means and SD. These were pooled into a combined mean and SD using the standard pooled-variance formula (Borenstein et al., 2021). The overall mean was calculated as a weighted average of subgroup means according to their sample sizes, and the pooled SD was computed in R studio using the Borenstein et al (2021) formula. Publication bias was assessed using visual inspection of a funnel plot and Egger's regression test (Egger et al., 1997; Higgins and Green, 2011). The funnel plot showed slight asymmetry, and Egger's test approached but did not reach statistical significance ($z = 1.93$, $p = .054$). These findings suggest limited evidence of publication bias, although small-study effects cannot be ruled out. The small number of studies and trials included within this meta-analysis resulted in the Egger's test being low power, making the borderline p-value result more likely.

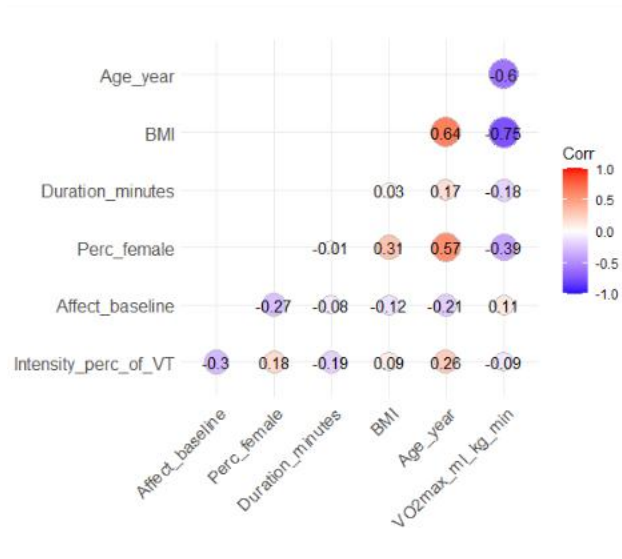


Figure 2. Collinearity check between moderators.

2.3: Results

Characteristics of the 27 trials from 14 studies are shown in **Table 1**. The posterior distribution of the meta-regression model suggests that although the mean effect size of exercise intensity relative to the VT is large (1.05), the 95% CI (−0.34, 2.41) includes zero, indicating uncertainty about the presence or direction of the effect (**Table 2**). The 95% CI for the effect sizes of all other moderators (baseline affective valence, sex, age, BMI, relative VO₂max, exercise duration) also include zero, similarly indicating uncertainty about the presence or direction of the effects (**Table 2**).

The direction of AV change during exercise (positive or negative) is also shown in **Figure 3**. At intensities above 100% of VT, AV is shown to decrease in all 7 trials, at intensities at 100% of VT 8 out of 9 trials decreased in AV, and at intensities below 100% of VT there is a heterogenous response to exercise with 7 out of 11 total studies reporting a decrease in AV. Of these 11 trials, 7 trials had a mean change in AV of 1.0 or less units on the FS (3 had a positive change, 4 had a negative change), whereas 4 trials observed a change in mean AV of >1 FS units (1 had a positive change, 3 had a negative change). The trend of these

mean AV changes for individual trials is shown in **Figure. 4**. The mean change across all trials is not positive at any intensity, including 80% of VT. **Figure. 5**. shows the Forest plot of the non-linear model detailing the effect of exercise intensity when moderators are at their means within each trial.

Table 1: Study characteristics

Reference	Sample size	Sex (% women)	Age (y)	BMI (kg·m ⁻²)	VO _{2max} (mL·kg ⁻¹ ·min ⁻¹)	Exercise intensity (% VT)	Exercise duration (min)	Baseline affective valence	Lowest affective valence	Highest affective valence	Greatest deviation in affective valence	Protocol considerations
Bird et al (2019)	18	50	24.17	22.98	37.07	100	10	4.33	2.5	4.33	-1.83	Cycle Ergometer
Bogdanis (2021)	12	50	21.7	23.2	44.5	80	20	4.7	1.6	4.7	-3.1	Treadmill
Bogdanis (2021)	12	50	21.7	23.2	39.9	80	20	4.7	2.6	4.7	-2.1	Cycle Ergometer
Decker and Ekkekakis (2017)	24	100	39.25	34.96	19.05	90	25	3.19	1.12	3.19	-2.07	Recumbent Cycle Ergometer
Dierkes et al (2021)	40	72.5	27.0	23.6	31.4	90	60	2.67	2.67	3.1	0.43	Cycle Ergometer
Ekkekakis et al (2008)	30	46.67	21.36	22.72	52.47	80	15	3.17	3.17	3.54	0.37	Below VT, Treadmill
Ekkekakis et al (2008)	30	46.67	21.36	22.72	52.47	100	15	3.01	2.21	3.01	-0.8	At VT, Treadmill

Ekkekakis et al (2008)	30	46.67	21.3 6	22.72	52.47	110	15	2.88	0.86	2.88	-2.02	Above VT, Treadmill
Hargreave s and Stych (2013)	21	100	42.5	26.5	27.6	100	20	1.0	1.0	2.19	1.19	At VT, Treadmill
Hargreave s and Stych (2013)	20	100	42.9	27.0	29.0	110	20	2.05	0.2	2.05	-1.85	Above VT, Treadmill
Hoekstra et al (2017)	12	0	22.5	23.46	35.5	80	30	3.25	2.25	3.25	-1.0	Arm Crank
Jones and Ekkekakis (2019)	21	76.19	34.6 7	28.56	24.21	100	15	2.38	0.13	2.38	-2.25	Recumbent Cycle Ergometer
Kilpatrick et al (2007)	37	45.95	23.9	25.2	34.91	85	30	2.32	1.59	2.32	-0.73	Below VT, Cycle Ergometer
Kilpatrick et al (2007)	37	45.95	23.9	25.2	34.91	105	24	2.38	0.05	2.38	-2.33	Above VT, Cycle Ergometer
Kinghorn et al (2026)	29	62.07	23.9 7	23.39	39.45	80	30	2.17	1.62	2.17	-0.55	Below VT, Cycle Ergometer
Kinghorn et al (2026)	29	62.07	23.9 7	23.39	39.45	100	30	2.07	0.66	2.07	-1.41	At VT, Cycle Ergometer

Kinghorn et al (2026)	29	62.07	23.9 7	23.39	39.45	110	30	2.69	-0.27	2.69	-2.96	Above VT, Cycle Ergometer
Niven et al (2018)	12	0	25.0	24.42	48.2	85	30	2.1	2.1	2.3	0.2	Below VT, Cycle Ergometer
Niven et al (2018)	12	0	25.0	24.42	48.2	105	22.1	2.1	0.7	2.1	-1.4	Above VT, Cycle Ergometer
Prado et al (2021)	14	100	24.3	23.66	41.6	80	15	1.0	1.0	2.36	1.36	Luteal Phase, Below VT, Treadmill
Prado et al (2021)	14	100	24.3	23.66	41.6	110	15	0.57	-2.0	0.57	-2.57	Luteal Phase, Above VT, Treadmill
Prado et al (2021)	14	100	24.3	23.66	41.6	80	15	3.07	2.5	3.07	-0.57	Follicular Phase, Below VT, Treadmill
Prado et al (2021)	14	100	24.3	23.66	41.6	110	15	2.86	-0.36	2.86	-3.22	Follicular Phase, Above VT, Treadmill
Rose and Parfitt (2012)	17	100	43.9	26.5	31.1	100	30	2.47	2.29	2.47	-0.18	Sedentary, Treadmill
Rose and Parfitt (2012)	15	100	46.4	24.8	40.0	100	30	3.28	2.73	3.28	-0.55	Active, Treadmill
Zenko and Ekkekakis (2019)	58	100	26.0	24.7	29.26	100	10	2.93	1.79	2.93	-1.14	Female, Recumbent Cycle Ergometer

Zenko and Ekkekakis (2019)	37	0	23.0	25.51	35.63	100	10	2.92	2.39	2.92	-0.53	Male, Recumbent Cycle Ergometer
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Values shown are mean (SD)

Table 2: Non-Linear Bayesian Model Results

Linear terms (%VT rcs; 3 knots)

Param	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	1.7626	0.3436	1.0742	2.4328	1.0007	13,808.359 1	7,870.9362
Affect Baseline	0.3900	0.3579	-0.3194	1.0870	1.0009	13,847.117 9	6,606.8580
% female	-0.0030	0.0133	-0.0293	0.0228	1.0003	8,903.4109	8,057.3972
Age (yr)	0.0514	0.0697	-0.0837	0.1877	1.0000	9,073.9799	7,630.5734
BMI	0.0190	0.0250	-0.0314	0.0672	1.0001	7,796.6256	7,718.9371
Rel VO2max	-0.1456	0.2010	-0.5456	0.2442	1.0002	6,858.2456	7,496.1072
Duration_ minutes	0.0244	0.0650	-0.1022	0.1521	1.0005	7,165.2050	7,164.8936
s(Ex Intensity)	1.0506	0.6943	-0.3431	2.4135	1.0003	11,992.095 5	7,957.5478

. Estimate = posterior mean; Estimate Error = posterior standard error; 95% CI = 95% credible interval for the posterior estimate.
Rhat = Gelman–Rubin convergence statistic (values ≈ 1 indicate convergence). Bulk ESS and Tail ESS = effective sample sizes
assessing reliability of estimates in the centre and tails of the posterior distribution.

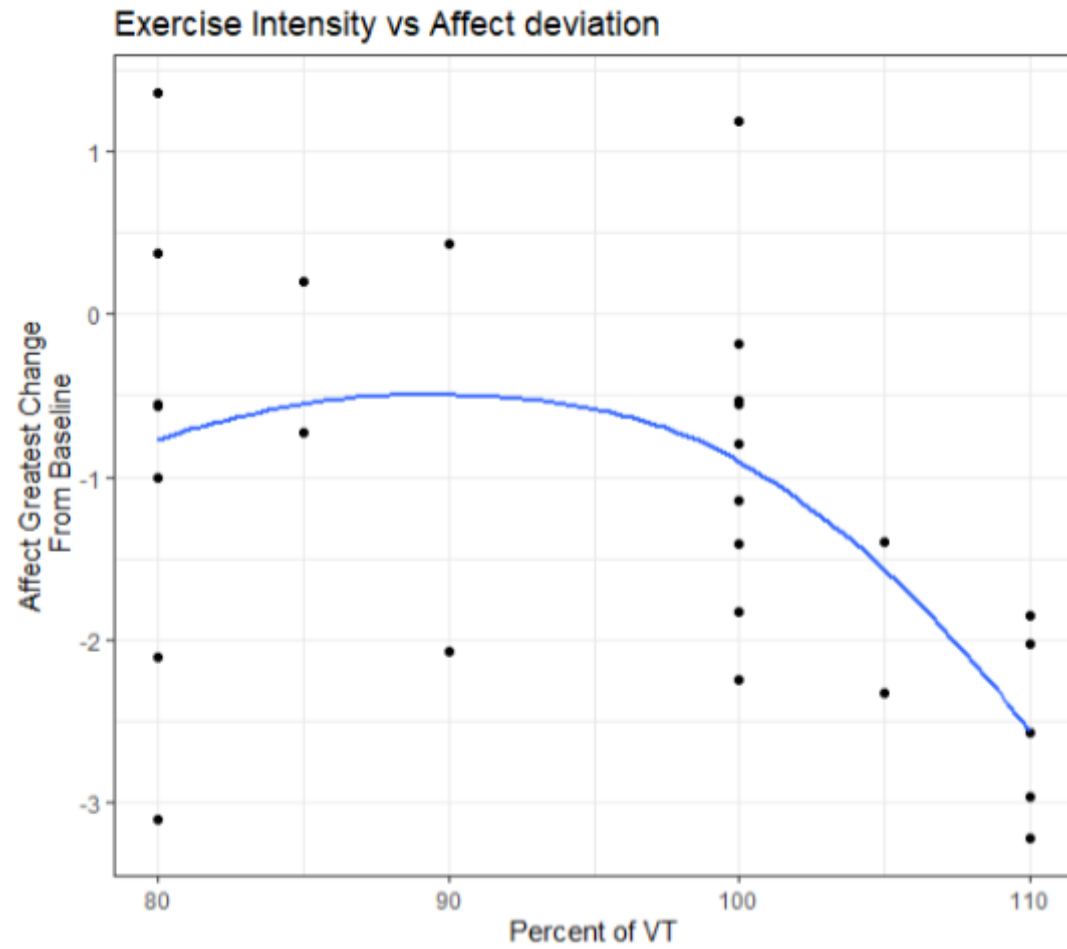


Figure 4. The relationship between the mean change in AV of each individual outcome and exercise intensity. The mean change trend line remains at below 0 values throughout.

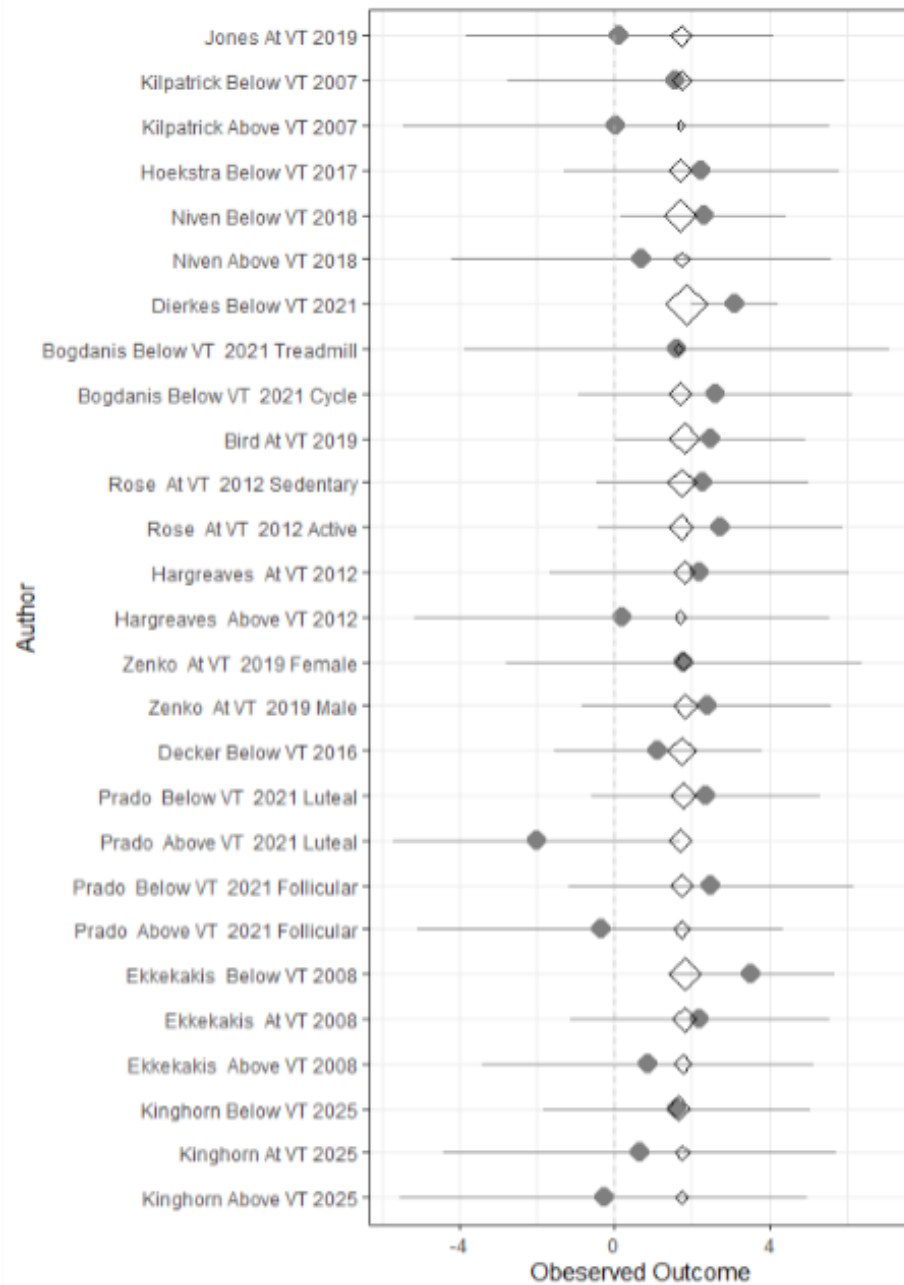


Figure 5. The non-linear model forest plot. The forest plot shows the original study estimates as grey circles with 95% confidence limits ($1.96 * SD_GD$). The model estimated effects are shown as open diamonds scaled to the variability of the estimate.

2.4: Discussion

The main aim of this study was to meta-analyse the available literature to identify whether the hypothesis of the DMM that exercise below the VT elicits a homogenous improvement in AV, exercise at the VT elicits a heterogeneous response, and exercise above the VT elicits a homogenous decrease in AV, can be confirmed. Using data from 733 participants from 14 studies, the main finding of this meta-analysis is that exercise at intensities below 100% of the VT does not elicit a homogenous increase in AV from baseline values as the DMM theorises. 7 of the 11 trials that implemented exercise at intensities below 100% VT showed a mean decrease in AV during exercise from baseline values, including 5 of the 7 trials at an intensity of 80% of the VT. The findings from trials involving exercise at intensities at or above 100% of the VT do provide some support for the DMM theory in that the VT may be a turning point for changes in AV during exercise, as every trial at intensities at or above 100% of the VT showed mean decreases in AV except for the Hargreaves and Stych at 100% VT trial (2012). However, the DMM is disputed as the trend shows a mean decrease in AV starting at exercise protocols below 100% of the VT. The efficacy of alternative exercise protocols, particularly HIIE and SIE protocols, as suitable interventions for inactive and sedentary populations has been heavily criticised by authors within the field (Hardcastle et al., 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2020), primarily due to the authors' assumption that the vigorous and supramaximal intensities of the protocols far supersede the domains detailed in the DMM and therefore must elicit feelings of displeasure so great that inactive and sedentary populations will not adhere long-term. However, as shown by our results, assumptions about AV change during exercise based off exercise intensity according to the DMM are unfounded. This aligns with other seemingly paradoxical findings within the field that show that, despite typically sharper drops in AV during exercise, HIIE protocols are not enjoyed any less than MICE protocols (Jung et al., 2014; Heisz et al., 2016; Stork et al., 2017; Thum et al., 2017; Oliveira et al., 2018; Stork et al., 2018; Guilkey et al., 2023). Intensity, therefore, must not be the only key determinant of AV change during exercise and future studies should move away from solely using the DMM framework to set exercise protocols for inactive and sedentary populations.

While none of the moderators assessed within this meta-analysis provided any statistical effect, there are some notable findings from individual studies that are worth mentioning. Ekkekakis et al., (2010) reported lower AV responses in obese women (Obesity is categorised as a BMI greater than 30kg/m^2 ;) when compared to non-obese women during an incremental treadmill protocol, with Ekkekakis et al (2016) suggesting that obesity may result in negative AV responses during exercise at any intensity rather than the DMM's hypothesised homogenous increase. Only one of the 11 trials from 9 studies that investigated exercise at intensities below 100% of the VT (Decker and Ekkekakis, 2017) had participants report a mean BMI within the 'obese' category (34.96 kg/m^2), also finding a large decrease in AV from baseline (-2.09 FS units). Participants from one other study (Kilpatrick et al., 2007) reported a BMI above the 'healthy' range ($18\text{-}25\text{ kg/m}^2$; 25.2 BMI), and they also reported a mean AV decrease (-0.73). All trials at intensities below 100% of VT that reported improvements in AV also reported healthy BMIs. Sarma et al., (2021) state obesity estimates worldwide to be 5% of the population for children, and 12% of the adult population (~ 108 million and 604 million respectively), with the prevalence of obesity doubling in over 70 countries between 1980 and 2015. An estimated 40% of the global population is overweight ($>25.0\text{ kg/m}^2$) or obese ($>30.0\text{ kg/m}^2$) according to the BMI (Bentham et al., 2017), with multiple studies finding that overweight or obese adults exercise less frequently than those with healthy BMI ranges ($18\text{-}25\text{ kg/m}^2$) across a range of decades (Dishman and Gettman, 1980; Epstein et al., 1984; Kriska et al., 1986; Tryon et al., 1992; King et al., 2001; Bautista-Castano et al., 2004; Jakicic et al., 2018; Mahumud et al., 2021), with the trend expected to worsen (Jakicic et al., 2018). Ekkekakis and Lind (2006) reported that only one fifth of overweight American adults (22.2% of men and 19.0% of women) adhere to the minimum PA guidelines, with only 18.8% of obese men and 16.1% of obese women adhering to the PA guidelines. Global studies have reported that these overweight and obesity rates are continuing to accelerate (Stevens et al., 2012; Bentham et al., 2017; Chooi et al., 2019), yet only 8 out of 27 trials had participants with average BMI scores above the 'healthy' range of 25 kg/m^2 . Research looking at AV during exercise requires more studies looking at individuals with larger mean BMI scores. However, of the 20 trials that included participants with a mean healthy BMI, 16 reported decreases in AV. Of the 9 trials involving exercise at intensities

below 100% of the VT with participants with a mean healthy BMI score, 5 reported a decrease in AV. BMI may be a factor that influences AV change, but it is not the singular determinant of AV change during exercise.

Of the 8 trials including participants with a mean BMI above 25 kg/m² (Therefore classified as ‘overweight’ according to the BMI classifications), a singular trial (Hargreaves and Sytch, 2012) showed an increase in mean AV, though this study had a low baseline AV of 1.0 on the FS, which could explain the increase. This is noticeably low as only three of the 27 trials had a mean baseline AV of less than 2 FS units (Hargreaves and Sytch, 2012; and both Prado et al., 2021 Luteal phase trials) with the lower intensity (80% of the VT) Prado et al (2021) trial showing a mean increase of 1.31 FS units. Of the three trials with a baseline AV of 1 or less, only one trial out of the three showed a mean decrease in AV, likely due to the intensity being 110% of VT (Prado et al., 2021). Interestingly though, Baseline AV was found to have no credible effect as a moderator of AV during exercise. Concurrently, two trials that started with noticeably high baselines (two arms of Bogdanis et al., 2021; only 4 trials out of 27 had baseline AV scores of 4 or greater) reported large decreases in AV (-3.1 and -2.1) despite lower intensities of 80% of VT. All 4 trials with a baseline AV of 4 or greater saw decreases in AV of 1.4 FS units or more. The greatest positive mean change at intensities below 100% of VT was 1.36 FS units (15 min treadmill, 80% VT). The greatest negative mean change at intensities below 100% of VT was -3.1 FS units (20 min treadmill, 80% VT). The studies had similar values for all moderators aside from baseline affect. Given that baseline AV was not found to have a credible moderating effect on AV change, there must be another factor that has influenced AV change within these specific trials. How participants are introduced to a study and their base feeling is potentially very important as to how they will feel during the exercise itself. If a participant is already feeling as good as the scale allows, the only way they can change is to feel worse, and visa-versa. Research also needs to be conducted looking at the language used by researchers, both in person and in participant information sheets. The language chosen by the researcher, whether positive or negative, may influence an individual’s

affect (Knuppenburg and Fredericks, 2021), and in turn may predict how an individual perceives a task (in this case exercise), though this has not been specifically investigated.

A clear limitation of this meta-analysis was the relatively small data pool available (733 participants from 27 trials, with only 397 unique participants from 14 studies) to analyse exercise at intensities relative to the VT without any additional interventions, or self-selected variance of intensity during the exercise duration. This means the ability of this meta-analysis to precisely establish the effect of exercise intensity and other potential moderators is reduced. A potential solution for this would be to include any measurement of AV during exercise other than the FS that give a baseline measure and in-task measurements at various timepoints. As the FS is the gold standard, these studies may be harder to come by but standardising all AV measurements into z-scores would increase the power of this analysis, if such studies exist that measure AV during exercise at intensities relative to the VT. It is irrefutable that multiple trials utilising exercise at intensities below 100% of VT had mean decreases in AV, as opposed to the homogenous increase theorised by the DMM. So, while the power of this meta-analysis may have been low, important conclusions can still be drawn regarding the legitimacy of the argument against the DMM. 13/27 trials consisted of 20 or fewer participants, and only two trials had more than 40 participants (2 trials from Zenko and Ekkekakis, 2019; 95 participants). Larger scale studies are required in this field to properly identify the effect of exercise intensity and other potential moderators. Exercise intensity had a large effect size (>0.8), but the lack of power means that the effect size was not found to have a credible effect on AV change score (using 95% credible intervals for Bayesian statistics). Only 6 of the 25 trials used MICE protocols lasting 30 min or more. A checklist produced by Ekkekakis and his team (Ekkekakis et al., 2023b) stated that when comparing differing exercise types while researching AV during exercise, MICE protocols should 'not deviate substantially from a total duration of approximately 30 min' to be comparable to the WHO guidelines of five 30 min bouts of exercise each week. 11 of the 27 trials lasted 15 min or less, with 3 trials lasting just 10 min. This study found no overall effect of duration on the AV change score, but this could be due to the power of the study. There is a need for more studies to research AV during exercise at longer

exercise durations, without any external modifiers of AV to the exercise, this would allow for a more statistically powerful meta-analysis in future. It is also necessary for more research looking at the effect of continuous exercise on AV in overweight and obese populations to fully understand the relationship between BMI and AV during exercise, just as Ekkekakis et al (2016) called for previously.

The ‘real life’ application of these findings is that how people feel during exercise is not solely dependent on what intensity they are working at. This refutes previous claims that MICE is the only acceptable exercise intervention for the general inactive population because it should make everyone feel ‘better’ while participating (Hardcastle et al., 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2020). MICE is a very important exercise type that is key to tackling the PI pandemic, but it cannot be proposed as the only solution to this issue.

To conclude, the results from this meta-analysis do not support the DMM’s theory that exercise at intensities below the VT elicit a homogenous increase in pleasure. The findings do show some support to the hypothesis that the VT is a turning point for AV responses during exercise.

2.5: Appendices

PSIS-LOO

Model	elpd_diff	se_diff	elpd_loo	se_elpd_loo
Nonlinear model	0.00	0.00	−50.46	1.12
Linear model	−0.02	0.58	−50.49	1.13

Appendix 1. Model comparison between linear and non-linear.

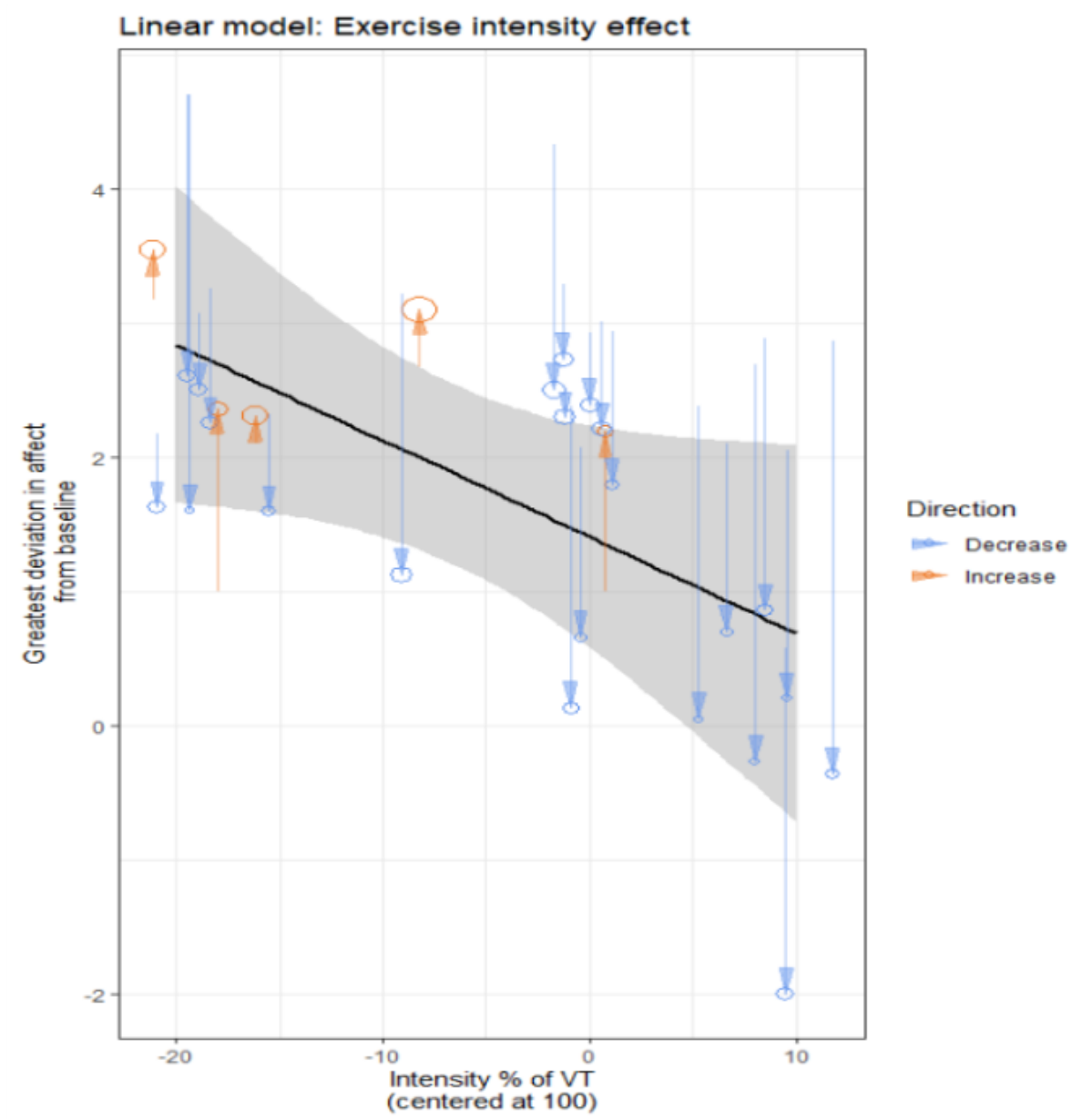
Bayesian Model Results

(No smooth terms)

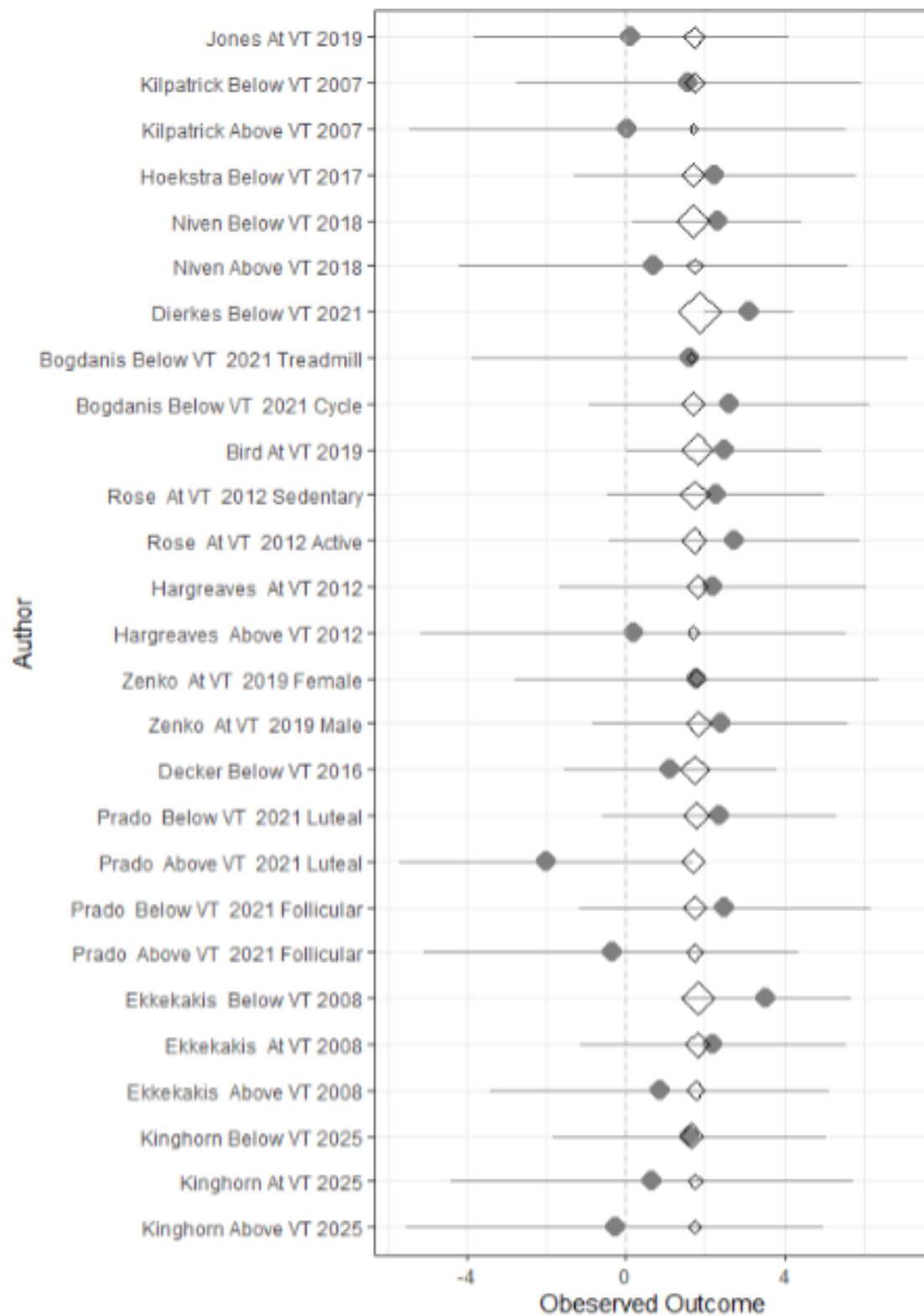
Param	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	1.4059	0.4254	0.5814	2.2363	1.0001	23,774.799 3	13,705.111 1
Ex Intensity	−0.0714	0.0374	−0.1443	0.0027	1.0002	19,660.726 7	13,911.001 8
Affect Baseline	0.3768	0.3629	−0.3363	1.0837	1.0000	23,463.055 1	14,425.795 7
% female	−0.0065	0.0129	−0.0317	0.0182	1.0003	20,665.992 6	14,935.482 3

BMI	0.0151	0.0249	−0.0351	0.0630	1.0001	12,523.249 4	13,008.139 1
Age (yr)	−0.2040	0.2019	−0.6009	0.1893	1.0000	12,645.548 6	13,419.413 0
Rel VO2max	0.0824	0.0695	−0.0528	0.2181	1.0003	17,275.144 3	14,143.516 2
Duration_ minutes	−0.0020	0.0639	−0.1273	0.1247	1.0001	13,469.521 1	13,920.821 5

Appendix 2. The linear Bayesian model



Appendix 3. Linear model waterfall plot.



Appendix 4. Linear model forest plot.

Chapter 3: A comparison of Affective Responses During Continuous and Interval Exercise

3.1: Introduction

Extensive efforts have been aimed at increasing PA levels within the population (Bull et al., 2020), with long-term exercise adherence key to reducing this risk (Rhodes et al., 1999; Imayama et al., 2013).

Despite this, many individuals do not meet PA guidelines (Bull et al., 2020; Strain et al., 2024).

Therefore, identifying factors that may influence PA levels in the general population is needed. AV, an individual's feelings of pleasure or displeasure has been shown to be modified by exercise (Ekkekakis et al., 2008; Songsorn et al., 2020). AV responses during exercise have been hypothesised to influence post-exercise remembered exercise enjoyment levels, compared to a pre-exercise baseline (Raedeke, 2007), and has been hypothesised to influence the uptake of and adherence to exercise.

Exercise intensity has been identified as the main catalyst for changes in AV with exercise (Welch et al., 2007; Ekkekakis et al., 2008). The DMM (Ekkekakis 2009; Ekkekakis et al., 2020) states intensity as the key factor impacting AV during exercise, with the VT as the key turning point, hypothesising that exercise at an intensity below the VT (moderate domain) will elicit a homogenous increase in positive AV, exercise at intensities between the VT and the RCP (heavy domain) elicits a heterogeneous AV response (some individuals will experience pleasure and some will experience displeasure), and exercise above the RCP (severe domain) elicits a homogenous decrease in AV. Evidence within the field does lend support to intensity being a key factor in the change in AV: with a greater intensity comes a greater decrease in AV (Blanchard et al., 2001; Ekkekakis et al., 2005; Oliveira et al., 2015). If true, the hypothesis from the DMM has important implications for exercise guidelines and interventions. Exercise protocols at intensities below the VT are most likely to lead to adherence to exercise, and exercise at

supramaximal and submaximal intensities, used in SIE and HIIE respectively, should not be recommended to the general public as they will be associated with unmanageable decreases in AV and unlikely to be adhered to (Ekkekakis et al., 2020).

HIIE and SIE have been promoted as time-efficient alternative exercise protocols to MICE, showing similar improvements to key health benefits (Macinnes and Gibala., 2017; Gillen and Gibala, 2018; Metcalfe and Vollaard, 2024). However, the usage of these protocols as interventions to improve PA levels has received criticisms (Hardcastle et al, 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2023a; Ekkekakis et al., 2023b). The health benefits are not contested (Hardcastle et al., 2014; Biddle and Batterham, 2015), but the supramaximal intensities of the sprint bouts fall within the severe domain proposed by the DMM and are therefore hypothesised to elicit large decreases in AV in all individuals (Ekkekakis et al., 2020). AV has been shown to decrease at a greater rate during HIIE/SIE than with MICE (Niven et al., 2021), and Metcalfe et al (2022) reported a negative relationship between number of sprint repetitions and AV responses during exercise. AV responses are predicted to lead to reduced remembered exercise enjoyment (Hardcastle et al., 2014), with enjoyment being hypothesised to predict exercise adherence (Parfitt and Hughes, 2009; Jekauc, 2015). Therefore, HIIE and SIE are hypothesised to be an unsuitable exercise intervention for sedentary and inactive populations (Ekkekakis et al., 2020). However, there are some inconsistencies within the evidence supporting the DMM. Data from one of the seminal studies used to form the DMM only partly support the hypotheses (Ekkekakis et al., 2008). There were significant, increasingly greater, negative decreases in AV responses during exercise performed at an intensity of 100% of the VT and 110% of the VT when compared with 80% of the VT. However, the data reports an initial increase in AV for the exercise at 80% of the VT during the warm-up period but then a steady decrease over the 15 min protocol to return to near baseline values, clearly showing a mean decreased affective response to the stimulus as opposed to the homogenous increase in AV while exercising at intensities below the VT hypothesised within the DMM. This is further evidenced by the finding that only 7% of participants reported a positive increase in AV, with 43% reporting a decrease.

Other studies investigating AV during MICE have reported similar gradual decreases in AV (Decker and Ekkekakis, 2017; Songsorn et al., 2020). Two further inconsistencies of the seminal data are 1) the usage of very fit individuals ($\dot{V}O_2\text{max}$: males $57 \pm 7 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, and females $48 \pm 8 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), reducing the relevance for sedentary and inactive populations, and 2) the duration of the exercise bouts performed. In a checklist for research involving AV responses to exercise, Ekkekakis and team recommend that MICE bouts should be kept between 30 and 45 min when comparing AV responses to other protocols, such as SIE and HIIE (Ekkekakis et al., 2023b). The three exercise conditions performed during the study by Ekkekakis et al (2008), lasted just 15 min each. Many continuous exercise protocols used in studies measuring AV responses to exercise are of a similar short duration (10-15 min; Tempest and Parfitt, 2013; Bird et al., 2019; Jones and Ekkekakis, 2019), making establishing the effect of duration on continuous exercise difficult.

Another inconsistency of the DMM is that the hypotheses do not necessarily apply to interval exercise. The recovery periods between the high-intensity bouts may lead to different AV responses than with continuous exercise as individuals can anticipate the 'easy' recovery period. Three recent meta-analyses have found that HIIE is not enjoyed any less than MICE (Stork et al., 2017; Oliveira et al., 2018; Niven et al., 2021), with the study by Niven et al (2021) reporting that HIIE is found to be more enjoyable than MICE. Furthermore, a study by Songsorn et al (2020) found that the drop in AV with REHIT (a low-volume SIE protocol) was not significantly greater than the drop with MICE. It is possible that the attenuated drop in AV may be influenced by the short duration of the high-intensity bouts, but currently only one study has compared the decrease in AV in commonly used durations of MICE (30mins) with a supramaximal SIE protocol (Songsorn et al., 2020). In a number of publications on AV responses to exercise (Ekkekakis et al., 2011; Ekkekakis and Brand, 2019; Ekkekakis et al., 2020; Ekkekakis et al., 2024), the duration of the exercise bouts is not mentioned or proposed as a factor. In MICE the drop is expected to decrease much more slowly (Songsorn et al., 2020), but the gradual reduction over a longer period may lead to a greater duration spent at a reduced affective state compared to HIIE and SIE

protocols. The original key goal for SIE and HIIE protocols was to achieve key health adaptations in as low a total-time commitment as possible (Burgomaster et al., 2005; Gibala et al., 2006), with more recent protocols demonstrating that low-volume SIE protocols are associated with a range of key health benefits (Gillen et al., 2016; Ruffino et al., 2017; Cuddy et al., 2019; Metcalfe and Vollaard, 2024). Low volume in this sense refers to the total duration and number of sprint bouts within a given protocol. REHIT consists of 2 20s supramaximal sprints (40s volume) in a 10 min protocol compared to traditional SIE which consists of 4 30s sprints (2 min volume) in a 22 min protocol (Gibala et al., 2006; Metcalfe et al., 2012). Ignoring the duration of SIE and HIIE protocols ignores one of the key characteristics of that type of exercise intervention. The findings from the meta-analyses conducted by Stork et al (2017), Oliveira et al (2018), and Niven et al (2021), as well as the study by Songsorn et al (2020), give support to the possibility of an exercise intensity x duration effect that moderates the change in AV during exercise. The more sudden drop reported during HIIE and SIE (Songsorn et al., 2020; Niven et al., 2021) may decrease AV quickly, but experiencing a similar drop for a greatly increased duration may result in reduced remembered exercise enjoyment. Focusing on the drop in AV as a fluid concept over time as opposed to stating that the protocol with the lowest AV point is the 'least enjoyable' could explain why HIIE/SIE may be enjoyed more than MICE, despite the significantly greater intensities.

Therefore, by comparing exercise bouts of various durations and intensities, this study aims to elucidate whether remembered exercise enjoyment and changes in AV during exercise depend solely on exercise intensity or on exercise duration as well. It is hypothesised that high-volume SIE will be associated with a significantly greater drop in AV and remembered exercise enjoyment compared to MICE, but that this will not be the case with low-volume SIE.

3.2: Methods

3.2.1: Participants

29 medically healthy young men (n=11) and women (n=18) volunteered for this study (Table 1). Individuals aged <18 or >40 years, who answered yes to one or more questions of the physical activity readiness questionnaire (PAR-Q; Thomas et al., 1992), had a resting heart rate ≥ 100 bpm, and/or clinically significant hypertension (>140/90 mm Hg; Jones et al., 2019) were excluded from participation. 6 participants were classified as low active according to the international physical activity questionnaire (IPAQ; Craig et al., 2003), 12 classified as moderately active, and 11 classified as high active. According to reference standards for cardiorespiratory fitness (Kaminsky et al., 2022), one of our participants was in the bottom quintile for $\dot{V}O_{2\max}$, n=5 were in the 2nd quintile, n=7 in the 3rd quintile, n=10 in the 4th quintile, and n=6 were in the top quintile. Participants received £50 for their time and effort. Ethics approval was gained through the local University ethics committee (NICR 2023/14849). All participants provided written informed consent prior to participation. The study was registered on ClinicalTrials.gov (registration: NCT06140693).

Table 1: Participant characteristics

	Mean	SD
Age (y)	24.0	5.4
Height (cm)	170.5	9.1
Body Mass (kg)	68.5	13.3
BMI (kg/m ²)	23.4	3.2
BpSys (mmHg)	120.6	11.1
BpDia (mmHg)	71.2	7.4
Resting HR (Bpm)	72.3	11.2

VO₂max (ml/kg/min⁻¹)	39.5	6.5
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3.2.2: Study design and experimental procedures

Participants visited the lab 7 times. During the initial visit, participants gave signed informed consent before physical characteristics were recorded (Table 1), as well as current physical activity level (IPAQ), and potential health-related reasons why participation would not be appropriate (PAR-Q; general health questionnaire). Participants then completed a VO₂max test on a cycle ergometer (Lode, Groningen, The Netherlands) to determine aerobic capacity and VT. The test consisted of cycling at an initial 50 W, with the intensity increasing 1 W every 3 s until volitional exhaustion or an inability to maintain a pedalling frequency of 60 RPM. Expired O₂ and CO₂ was measured using a COSMED breath-by-breath gas analyser (Cosmed K5, Cosmed, Italy). VO₂max was determined as the highest value for a 15-breath rolling average of VO₂. The VT was determined by plotting the ventilatory equivalents for oxygen (VE/VO₂) and carbon dioxide (VE/VCO₂) over the course of the test and identifying the point at which there is a systematic increase in VE/VO₂ without a corresponding increase in VE/VCO₂ (Davis et al., 1979; Amann et al., 2006; Robertson and Marino, 2015). In order to ensure as objective a result as the Davis et al (1979) protocol can allow, 3 researchers, two of which are required to have previous experience in determining the VT using this method, triple checked the identification of the point of the first VT, as per Davis et al (1979)'s recommendation. The Davis et al (1979) protocol was selected to mirror the exact same protocol used during the Ekkekakis et al (2008) study, to allow for a more valid comparison of the results.

Participants then visited the lab for a second time to familiarise themselves with the continuous training intensities and the SIT sprints. For the continuous training, each participant cycled for 5 min at each of the 3 intensities. After the initial rapid increase in oxygen uptake (first 2-3 min), the resistance was adjusted to elicit the desired level of VO₂ (80%, 100%, and 110% of VO₂ at the VT). Following on from this,

participants were asked to complete two maximal sprints. Participants cycled against 25 W resistance for 1 min 40 s before completing a 20-s maximal sprint against a resistance of 7.5% of their first visit bodyweight. Once this sprint was completed, participants continued cycling against 25 W resistance for a further 3 min and 30 s before completing a 30-s maximal sprint against a resistance of 7.5% of the participant's bodyweight. After the second sprint was finished, participants continued cycling against 25 W resistance for a further 4 min before the session was completed.

The experimental sessions consisted of the three continuous exercise conditions and two SIE conditions in a randomised order so as to not introduce order effects. To further decrease the risk of bias the participants were not told which of the three intensities of continuous exercise they performed. For the three continuous training protocols, participants completed pre-exercise self-report measures. The FS for AV (Hardy and Rejeski, 1989) and the FA scale for in-task FA (Svebak and Murgatroyd, 1985).

For the continuous exercise sessions, participants warmed up by cycling for 5 min at 0.5 W/kg. During the final 15 s of the warm-up, AV and FA were recorded. The resistance of the cycle ergometer was then increased to a level that matched the selected intensity for that session. This resistance was maintained for the following 30 min. AV and FA were measured during the last 15 s of minutes 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30. Once the session was completed, participants began a 5-min cool-down by cycling at a 0.5 W/kg resistance. Remembered exercise enjoyment was recorded using the PACES questionnaire (Kendzierski and DeCarlo, 1991) 10 min after exercise completion.

For the first SIE session (here forth known as 'REHIT'), participants completed a 10-min cycle ergometer bout at 25 W resistance interspersed with two 20 s supramaximal sprints (Metcalf et al., 2012). AV and FA were measured at rest pre-exercise and then 15 s before each sprint, halfway through each sprint, 15 s into each sprint, at the completion of each sprint, and then 15 s after each sprint. AV and FA were also measured half-way through the low-intensity sections of the protocol, at 4:30 min, and 8:30 min, as well as at the completion of the session. remembered exercise enjoyment was recorded using the PACES questionnaire 10 min after exercise completion.

For the traditional SIT session, participants completed a 22 min cycling bout at 25 W resistance interspersed with four 30 s sprints (including a 4-min warm-up and 4-min recovery intervals after each sprint). AV and FA were measured at rest pre-exercise and then 15 s before each sprint, halfway through each sprint, 25 s into each sprint, at the completion of each sprint (4:30 min, 9 min, 13:30 min, 18 min), and then 15 s after each sprint. AV and FA were also measured half-way through the low-intensity sections of the protocol (6:30 min, 11 min, 15:30 min, and 20 min) as well as at the completion of the session. remembered exercise enjoyment was recorded using the PACES questionnaire 10 min after exercise completion. A diagram of all experimental protocols is included in the supplementary materials **(Supplementary Figure 8)**

For the final session (8th), the preference of exercise protocol was determined using the procedure proposed by Townsend et al (2017). For this, participants were asked to repeat one of the previous 5 exercise sessions to check consistency of the measurements. Their chosen protocol was recorded as their preference. The participants were informed after making this choice that they did not actually need to perform this session.

3.2.3: Statistical Analysis

All statistical analysis was performed in Jamovi (version 2.4.11) and R (RStudio 2023 4.3.2). Data are presented as means $\pm$ SD unless stated otherwise. To attempt to try a balance between sufficient temporal resolution of the AV responses and the ability to statistically analyse the AV responses, AV responses were summarised by determining the greatest deviation from baseline AV and FA for each participant for each trial, as suggested by Ekkekakis et al (2023). Area under the curve (AUC) data for the time and magnitude spent at a reduced AV (only including values below baseline. All other values were zeroed) was calculated using the trapezoid rule. Normal distribution for all tests was assessed using the Shapiro-Wilk test (Shapiro and Wilk, 1965). The below baseline AUC data were found to not be normally

distributed and thus was analysed using nonparametric tests where necessary. Paired samples T-tests were used to assess the difference in AV and FA from baseline with the greatest change (positive or negative) from baseline.

Pearson's correlation coefficient (Sedgwick, 2012) was used to measure correlation within participants, analysing the relationship between the drop in AV for each trial and participant characteristics (sex, age, BMI, relative VO_2max , Wmax , and activity level), in an attempt to identify factors moderating the change in AV during exercise. Pearson's correlation coefficient was also used to check for correlation in the drop in AV between protocols. Repeated measures ANOVAs were used to calculate differences in the drop in AV, FA change score, and remembered exercise enjoyment (using the PACES score) between the 5 trials, (with Bonferroni post-hoc comparisons where needed). A Friedman repeated-measures ANOVA with Durbin-Conover pairwise comparison, was used to assess differences in below baseline AUC score in all trials.

To further analyse potential moderating factors of AV change during exercise and remembered exercise enjoyment of the different exercise bouts, repeated measures correlations (Bakdash and Marusich, 2017) were used to assess the correlations between the mean power output (MPO) multiplied by duration (known henceforth as 'work done') and the greatest change in AV during exercise, and between remembered exercise enjoyment and the following factors: 1) the greatest change in AV during exercise, 2) below baseline AUC for AV, 3) the greatest change in FA, 4) exercise intensity (PPO was used for the sprint trials), and 5) work done. Statistical significance was accepted at $p < 0.05$.

3.3: Results

3.3.1: Trial characteristics

All participants completed all experimental trials, with no adverse effects reported. Exercise intensities (PPO for the SIE protocols) and work done during each of the five trials are shown in **Figure 1**. Exercise intensity was significantly higher during the sprint protocols compared to each of the three continuous exercise trials (all $p<0.001$; NS for REHIT vs. SIT). However, the reverse was true for work done (all $p<0.001$).

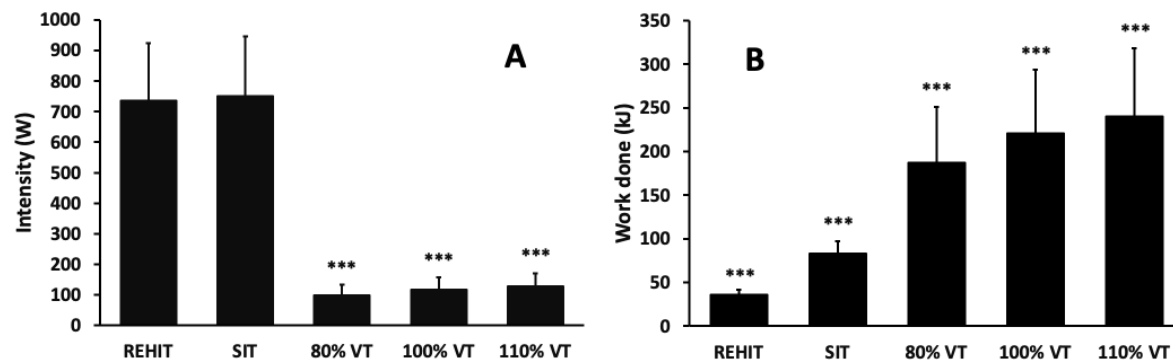


Figure 1 Peak exercise intensity (A) and total work done (B) for the 5 experimental trials. ***: $p<0.001$ for the difference with all other trials.

3.3.2: AV responses

AV significantly decreased from baseline during all exercise trials (80% VT: -1.38 ± 2.03 , $p<0.001$; 100% VT: -2.07 ± 2.25 , $p<0.001$; 110% VT: -3.62 ± 2.76 , $p<0.001$; REHIT: -1.45 ± 1.62 , $p<0.001$; SIT: -2.59 ± 2.40 , $p<0.001$) (**Figure 2**). For both REHIT and SIT, AV was significantly lower at the end of the second sprint when compared to baseline ($p<0.05$), with every subsequent repeated sprint significantly decreasing AV during SIE ($p<0.05$). FS value rebounded after each sprint but did not return to baseline values from the third sprint onwards during SIT (**Figure 2b**). All trials returned to baseline AV values 10 min post-exercise with no significant differences between trials.

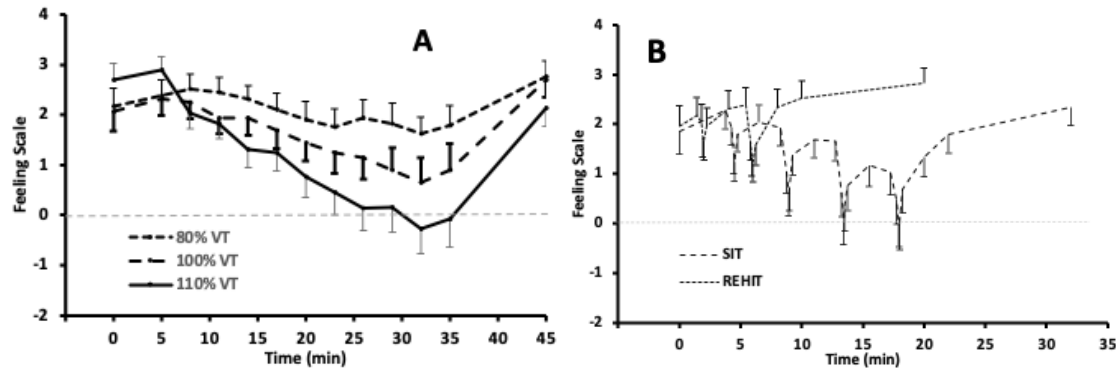


Figure 2 Affective responses during continuous exercise (A), and during supramaximal sprint exercise (B). Data are shown as mean $\pm$ SEM.

The timepoints recorded for the greatest change in AV were not consistent between participants and so the greatest change in AV from baseline was calculated for each individual (**Figure 3a**). The greatest change in AV from baseline was not significantly different between 80% VT, 100% VT, and REHIT, but significantly greater during 110% VT and SIT compared to each of these (REHIT vs SIT, $p=0.007$; REHIT vs 110% VT, $p<0.001$; 80% VT vs SIT, $p=0.005$; 80% VT vs 110% VT, $p<0.001$; 100% VT vs 110% VT, $p=0.007$), except for between the 100% VT trial and SIT.

The exposure to a reduced AV state was assessed by calculating the AUC for the time and magnitude of decreased AV responses compared to baseline values. REHIT had a significantly lower below baseline area under the curve than all trials (REHIT vs SIT, $p<0.001$; REHIT vs 80% VT, $p=0.043$; REHIT vs 100% VT, $p<0.001$; REHIT vs 110% VT, $p<0.001$). There was no significant difference between SIT, exercise at 80% of the VT, and exercise at 100% of the VT, but all three trials had a significantly lower score than exercise at 110% of the VT (SIT vs 110% VT, $p<0.001$; 80% VT vs 110% VT, $p<0.001$; 100% VT vs 110% VT, $p<0.001$).

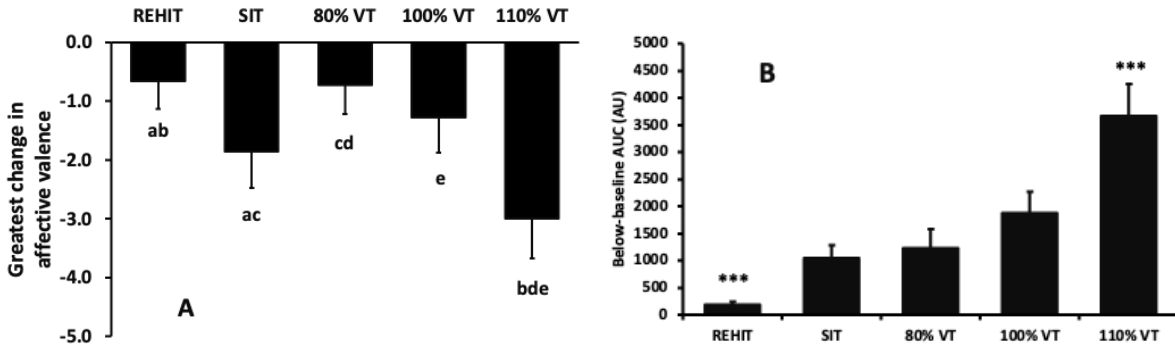


Figure 3 Greatest change in affective valence (**A**), and below-baseline AUC for time spend at reduced affective valence (**B**) for each trial. Data are shown as mean±SEM. Identical letters indicate a significant difference between trials; a: $p=0.007$, b: $p<0.001$, c: $p=0.005$, d: $p<0.001$, e: $p=0.007$. ***: $p<0.001$ for differences with all other trials (except REHIT vs. 80% VT: $p<0.05$).

The drop in affect during all 5 trials did not significantly correlate with any participant characteristics. The drop in AV with REHIT was significantly correlated with the drop in AV with SIT ($p<0.001$, $r=0.59$) but was not significantly correlated with the drop in affect with any of the three MICE trials. The drop in AV during 80% VT also significantly correlated with drop during SIT ($p=0.013$, $r=0.46$) but not 100% VT or 110% VT, which significantly correlated with each other ($p<0.001$, $r=0.69$).

3.3.3: FA change

FA significantly changed from baseline in all trials ($p<0.001$ for all; 80% VT: 1.34 ± 1.37 ; 100% VT: 1.72 ± 1.31 ; 110% VT: 1.93 ± 1.49 ; REHIT: 1.79 ± 1.29 ; SIT: 2.34 ± 1.52 ; **Figures 4 and 5**). There was no significant difference between the FA change scores of any of the 5 tests, except between SIT and 80% VT ($p=0.002$). There was a significant correlation in FA change score between all trials except REHIT and 110% VT ($p<0.05$ in all other trials).

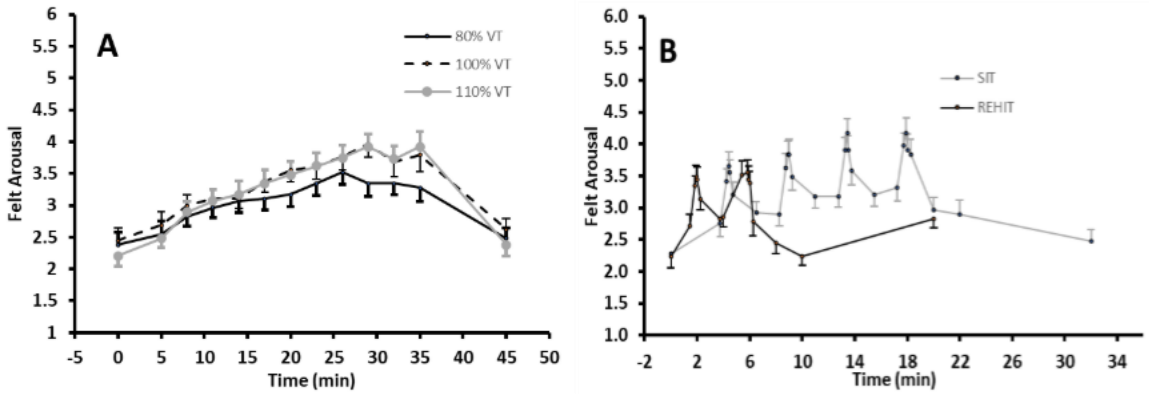


Figure 4 Felt arousal responses during continuous exercise (A), and during supramaximal sprint exercise (B). Data are shown as mean±SEM for clarity.

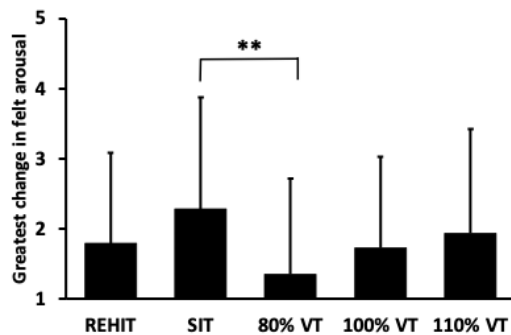


Figure 5 Greatest change in felt arousal for each trial. **: $p=0.002$ for the difference between SIT and 80% VT.

3.3.4: Remembered exercise enjoyment and exercise preference

Remembered exercise enjoyment was significantly greater for REHIT (88 ± 16) compared to both 110% VT (73 ± 20 , $p=0.003$) and SIT (71 ± 22 , $p<0.001$), but not significantly different from 80% VT (82 ± 18) or 100% VT (76 ± 21 ; **Figure 6**). There were no significant differences in remembered exercise enjoyment between any of the other trials. Accordingly, 21 out of 29 participants (72%) expressed a preference for REHIT (67% of low active participants, 83% of moderately active, 64% of high active), with $n=5$ preferring 80% VT, and $n=1$ each preferring 100% VT, 110% VT or SIT (**Figure 7**).

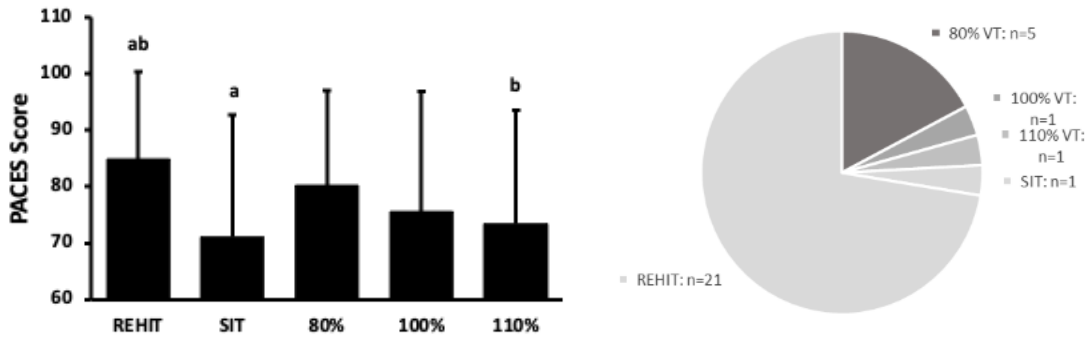


Figure 6 Remembered exercise enjoyment as assessed using the PACES questionnaire. Identical letters indicate a significant difference between trials; a: $p < 0.001$, b: $p = 0.003$. **Figure 7** pie chart of exercise preference.

3.3.5: Moderators of remembered exercise enjoyment

Repeated measures correlations were used to identify factors associated with remembered exercise enjoyment between the 5 trials. Significant small correlations were observed between remembered exercise enjoyment and 1) the change in AV during exercise from baseline ($p < 0.001$, $r = 0.40$, **Supplementary Figure 1**), 2) below baseline AUC score ($p < 0.001$, $r = -0.30$, **Supplementary Figure 2**), 3) the greatest change in FA ($p < 0.001$, $r = -0.32$, **Supplementary Figure 3**), and 4) total work done ($p = 0.017$, $r = -0.22$, **Supplementary Figure 4**). There was no significant correlation observed between Intensity (PPO) and remembered exercise enjoyment (**Supplementary Figure 5**). Lastly, total work done negatively correlated with remembered exercise enjoyment and the greatest change in AV ($p = 0.006$, $r = -0.25$, **Supplementary Figure 6**), but no correlation was observed between PPO and the change in AV during exercise (**Supplementary Figure 7**).

3.4: Discussion

The primary aim of this study was to elucidate whether remembered exercise enjoyment and changes in AV during exercise depend solely on exercise intensity or on exercise duration as well. The key findings support this our hypothesis that high-volume SIE will be associated with a significantly greater drop in AV and remembered exercise enjoyment compared to MICE, but that this will not be the case with low-volume SIE. Several notable findings were observed: 1) the data provides evidence against the theories that hypothesise exercise intensity to be the sole mediator of change in AV (DMM; Ekkekakis et al., 2020). REHIT was not associated with a greater drop in AV compared to exercise at 80% VT or exercise at 100% of the VT, despite REHIT sprints being supramaximal intensities (7.7-fold greater and 6.4-fold greater respectively). REHIT was also associated with a significantly smaller decrease in AV during exercise compared to exercise at 110% of the VT (5.9-fold lower). The significantly greater power outputs during the sprint trials (no significant difference in power output between sprint trials) compared to MICE elicited sharp decreases in AV, but the overall drop in AV was attenuated due to the very short duration of the sprints. This allows for the conclusion that intensity is not the sole determinant of AV change during exercise.

2) Our data demonstrates the existence of an exercise intensity x duration interaction on the change in AV responses during exercise. We showed that all three MICE trials elicited a progressive gradual decrease in AV over time, and that, despite similar PPO and MPO during the sprint bouts, SIT was associated with a significantly greater decrease in AV responses when compared to REHIT. Lastly, there was a significant correlation between work done and the greatest change in AV during exercise, but there was no correlation observed between exercise intensity and the greatest change in AV during exercise. While supramaximal intensities are associated with a faster decline in AV during exercise, this effect can be mitigated by reducing the duration of the exercise bout.

3) The results of this study challenge the hypothesis of the DMM (Ekkekakis et al., 2020) that exercise at intensities below 100% of the VT will elicit a homogenous increase in positive AV (Ekkekakis et al., 2008). While exercising at an intensity of 80% of the VT, AV decreased in 51% of participants (15/29), remained neutral in 14% (4/29), and increased in 34% (10/29). These findings indicate a clear heterogenous response.

4) Finally, we observed a significant correlation between the change in AV during exercise and remembered exercise enjoyment. Due to the significant difference in both AV responses and remembered exercise enjoyment observed between REHIT and SIT, aligning with the findings reported by Metcalfe et al (2022) that AV responses during SIE protocols negatively correlate with sprint duration, supramaximal interval exercise can be perceived as at least as enjoyable as MICE if the volume of exercise is kept low.

These findings align with current literature on the effects of exercise on remembered exercise enjoyment and AV responses during exercise. The meta-analysis by Metcalfe et al (2022), reported that the negative AV responses associated with SIE sessions can be attenuated by reducing the number of sprint repetitions and/or the duration of each sprint repetition. Although the present study did not independently manipulate sprint number and duration, the REHIT and SIT protocols in this study differed in both the number of repetitions and the duration of each sprint. REHIT incorporated fewer and shorter sprints compared with SIT, and this was accompanied by more favourable AV responses. Therefore, while the individual contribution of sprint number versus sprint duration was not statistically isolated, the observed differences between protocols are consistent with the suggestion that reducing sprint exposure attenuates negative affective responses. As discussed in **Chapter 2** multiple studies researching continuous exercise at intensities below the VT have reported decreases in AV (Kilpatrick et al., 2007; Decker and Ekkekakis, 2017; Niven et al., 2018; Bogdanis et al., 2021; Prado et al., 2021), aligning with the findings of this study that demonstrated MICE (at 80% of the VT and 100% of the VT) elicits a gradual mean decrease in AV responses and a heterogenous interindividual response, challenging the DMM's hypothesis of a homogenous increase in pleasure (Ekkekakis et al., 2008). We have also offered more evidence to support

the findings of recent meta-analyses that HIIE and SIE protocols can be enjoyed equally or greater than MICE (Stork et al., 2017; Oliveira et al., 2018; Niven et al., 2021). The findings from this present study are therefore expected. However, this is the first time the effects of various intensities of MICE and durations of SIE protocols have been compared within a singular study.

As stated in the introduction to this chapter, HIIE and SIE protocols have been heavily criticised as potential exercise interventions for sedentary and inactive populations (Hardcastle et al, 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2023a; Ekkekakis et al., 2023b). AV responses during exercise have been investigated due to their hypothesised influence on the uptake of and adherence exercise (Williams, 2008; Lacharite-Lemieux et al., 2015; Williams et al., 2016), with exercise intensity as the focus of these research efforts (Ekkekakis and Petruzzello, 1999; Welch et al., 2007; Ekkekakis et al., 2008). Exercise at lower intensities is proposed to result in homogenously increased AV, leading to increased remembered exercise enjoyment, leading to improved PA levels (Ekkekakis and Acevedo, 2006; Ekkekakis et al., 2008; Ekkekakis, 2009; Ekkekakis and Brand, 2019; Ekkekakis et al., 2020), with HIIE and SIE protocols hypothesised to lead to reduced enjoyment and as such are unlikely to be suitable as real-world interventions (Hardcastle et al., 2014; Biddle and Batterham, 2015). However, the findings of this present study dispute the effect of intensity as the sole moderator of AV and reject the proposed criticisms of high-intensity protocols. Greater exercise intensities are associated with greater decreases in AV, with the change in AV during exercise negatively correlating with remembered exercise enjoyment, but we have also demonstrated the effect of duration as a moderator, as evident with the significant difference in AV between the REHIT and SIT protocols in this study. The seminal data reported by Ekkekakis et al (2008) showed an initial increase in AV during the warm-up (5-min), followed by a consistent decline over the 15 min duration, with the rate of the decline determined by the intensity of the protocol. For this present study, we increased the MICE duration from 15 min to 30 min and demonstrated that, while the rate of the decline did not change, the absolute mean AV decrease was greater, giving further evidence to exercise duration being a moderator of AV change. These findings, and the findings of the present study that show negative AV

responses are attenuated if the sprint bouts are kept short, strongly support the existence of an exercise intensity x exercise duration effect that can explain the supposed contradiction that HIIE and SIE can be experienced as more pleasant and more enjoyable than MICE (Oliveira et al., 2018; Niven et al., 2021; Tavares et al., 2021). It is still currently unknown what mechanisms cause the steeper drop in AV responses during exercise at higher intensities. The DMM proposes that AV responses during exercise are influenced primarily by cognitive factors (e.g., self-efficacy, goals) at intensities below 100% of the VT and primarily interceptive factors (e.g., ventilation, acidosis) at intensities above the RCP. Our findings suggest that the brief duration of supramaximal sprints may negate the hypothesised effect of interceptive cues on AV responses.

The negative correlation observed between remembered exercise enjoyment and changes in FA is a novel finding. The relationship between FA and AV during exercise typically demonstrates that an increase in FA coincides with a decrease in AV (Kilpatrick et al., 2007; Ekkekakis et al., 2008). Despite this, and the hypothesised link between AV and enjoyment (Raedeke, 2007), the relationship between arousal and remembered enjoyment has not been studied. According to the circumplex model, the increase in FA and decrease in AV places individuals in the high-activation displeasure quadrant (Russell, 1980; Posner et al., 2005; Evmenenko and Texeira, 2022), which could be perceived as an overwhelming, and typically negative, experience. Future research is required to investigate the effect of changes in FA on exercise enjoyment. The data from this study show that, despite the FA and AV measurements being taken at multiple timepoints throughout the sprints without sacrificing sprint performance (similar power values compared to previous studies; Ruffino et al., 2017; Metcalfe et al., 2018; Metcalfe and Vollaard, 2024), the lowest values for AV responses were reported at the end of each sprint, suggesting that it is unnecessary for future studies to replicate the high volume of intra-sprint measurements.

Our findings contribute to the persisting debate on the efficacy of HIIE/SIE as suitable interventions for improving PA levels. The DMM (Ekkekakis et al., 2020) and Affective-Reflective Theory (Ekkekakis and Brand, 2019) may not accurately predict the relationship between AV responses, exercise intensity, and

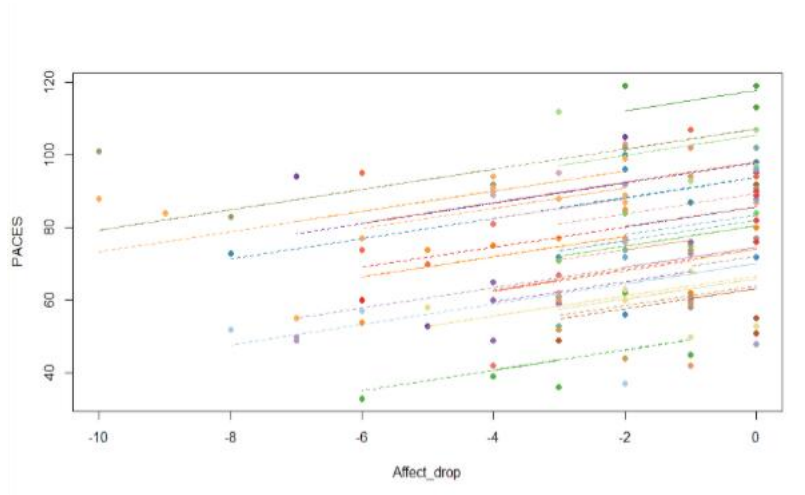
remembered exercise enjoyment, potentially criticising the efficacy of HIIE and SIE as exercise interventions prematurely. We have demonstrated that REHIT is not enjoyed less than continuous exercise and is actually preferred to the continuous exercise alternatives, despite the greatly increased intensity. A focus on research investigating the feasibility of supramaximal low-volume SIE protocols for improving PA levels in the general public is required. This study also showed large interindividual variability within the AV responses to each trial. This correlates with **Chapter 4**, and the findings by Songsorn et al (2020) and Ekkekakis et al (2008), who also showed heterogeneous AV responses to various exercise protocols. It is currently unknown what factors may influence this variability but understanding if the individuals who report a greater negative AV response are also more likely to discontinue an exercise routine could be important for improving PA levels and influences the written guidelines.

Our study was not without limitations. VO_2 and HR were not measured during the exercise sessions to remove some of the burden from participants. This did not allow us to confirm that participants exercised at the exact intensities relative to the VT throughout the protocols. RPE was not assessed during the sprints for a similar reason, collecting three numerical values at each time point was shown to be too difficult during pilot testing. These measures, as well as other potentially relevant measures such as $[\text{La-}]$ (Astorino and Vella, 2018) and the Preference for and Tolerance of the Intensity of Exercise Questionnaire (PRETIE-Q; Box et al., 2023), could have further evidenced our findings while potentially providing other moderators of AV change and remembered exercise enjoyment. This study also used a mix of PA levels and fitness levels. As the interventions are debated on their efficacy as interventions for inactive and sedentary populations (Ekkekakis et al., 2020), it could be argued that only these populations should have been recruited. We demonstrated that neither PA levels nor cardiorespiratory fitness were moderators of the change in AV during exercise or remembered exercise enjoyment. This finding requires confirmation in future studies, as well as confirmation of the findings of this study in an inactive and sedentary only trial. As previously discussed, the inclusion of multiple timepoints during the exercise sessions was necessary to gain temporal knowledge. However, the volume of these measurements warranted the use of summary

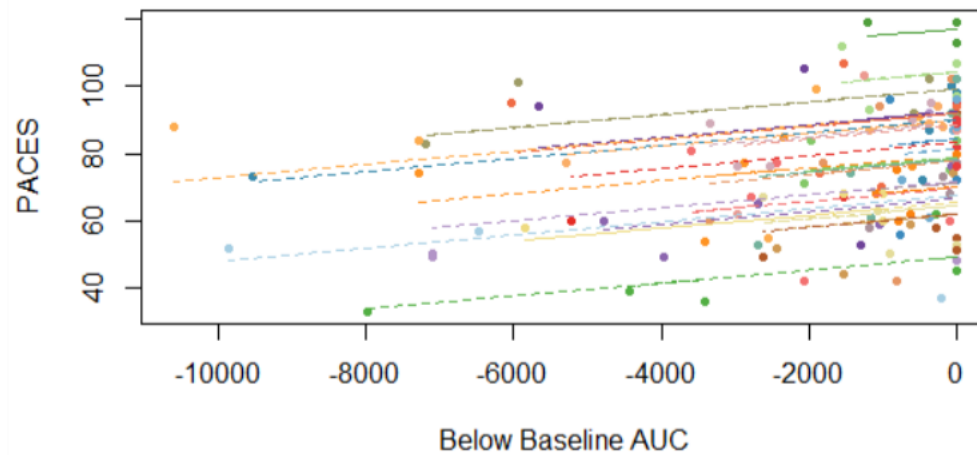
statistics (e.g. the change in AV during exercise), limiting the ability to perform more specific analysis on the changes at specific timepoints during the exercise bouts (Ekkekakis et al., 2023b). The reported decrease in AV during the SIT protocol was lower than reported in other studies (Stork et al., 2015; Townsend et al., 2017; Marques et al., 2020), potentially influencing the results of this study. However, as participant characteristics did not influence the change in AV during our study, it is difficult to assert what caused the variance in AV responses between studies.

To conclude, this study presents multiple novel findings and clearly demonstrates the existence of an exercise intensity x exercise duration interaction. The sharp drop in exercise associated with SIE can be attenuated if the duration of the sprint bouts is kept short. This, combined with low-volume SIE eliciting effective health benefits (Metcalf et al., 2012; Metcalf et al., 2015; Metcalf and Vollaard, 2024), may suggest that supramaximal exercise protocols can be effective interventions for public health. Our findings show that low-volume SIE is enjoyed equal to or greater than MICE and is preferred by the majority of participants, suggesting that future research into AV responses during exercise should not exclusively focus on exercise intensity, but instead acknowledge the effect of the intensity x duration interaction.

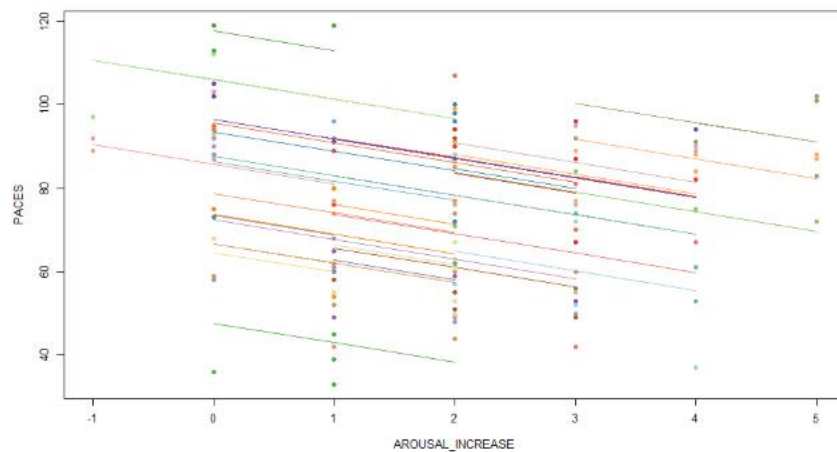
3.5: Supplementary Figures



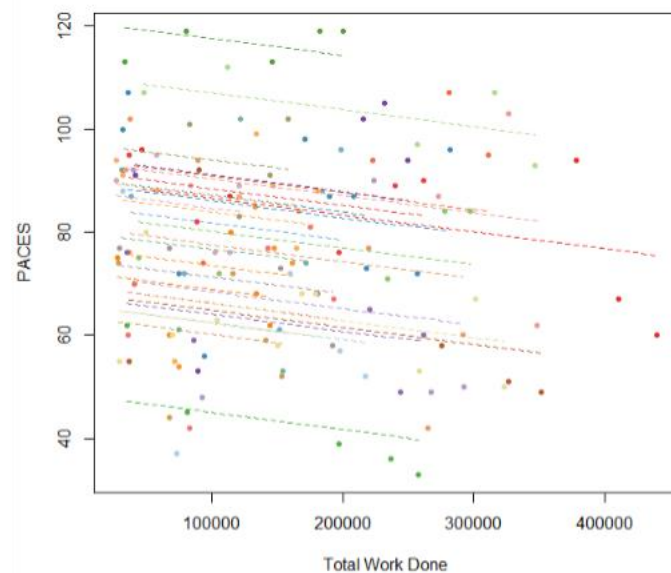
Supplementary Figure 1. Repeated measures correlation between remembered exercise enjoyment and the greatest change in affective valence from baseline ($r^2=0.16$; $p<0.001$). Data are presented as individual points for each trial with a correlation trendline for each subject.



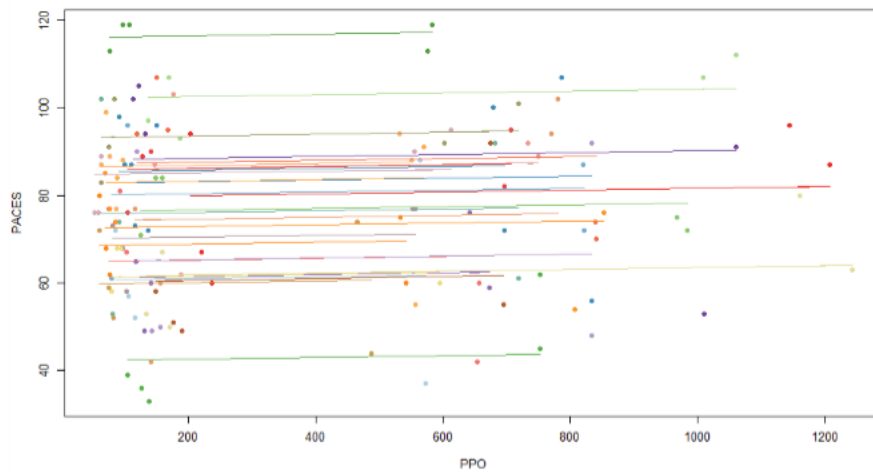
Supplementary Figure 2 Repeated measures correlation between remembered exercise enjoyment and below baseline AUC ($r^2=0.09$; $p<0.001$). Data are presented as individual points for each trial with a correlation trendline for each subject.



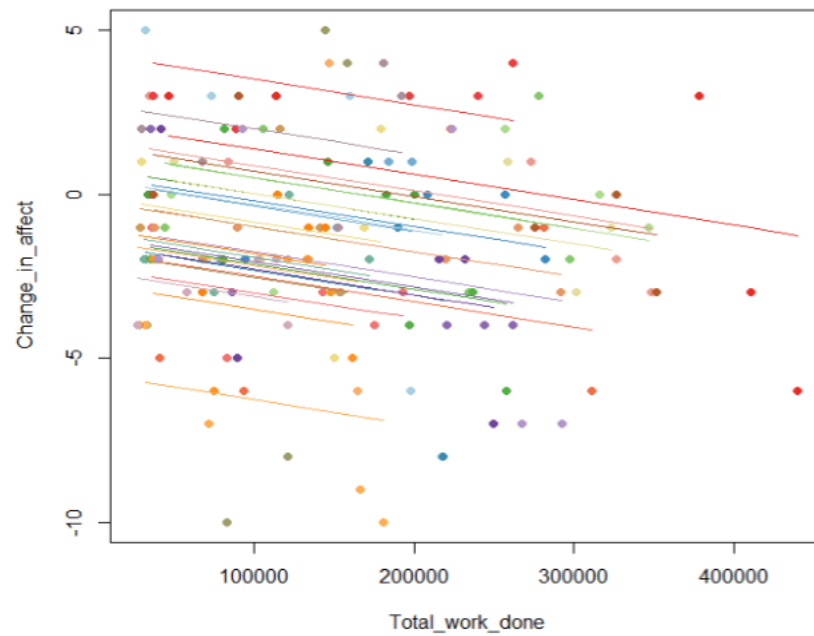
Supplementary Figure 3 Repeated measures correlation between remembered exercise enjoyment and the greatest change in arousal ($r^2=0.10$; $p<0.001$). Data are presented as individual points for each trial with a correlation trendline for each subject.



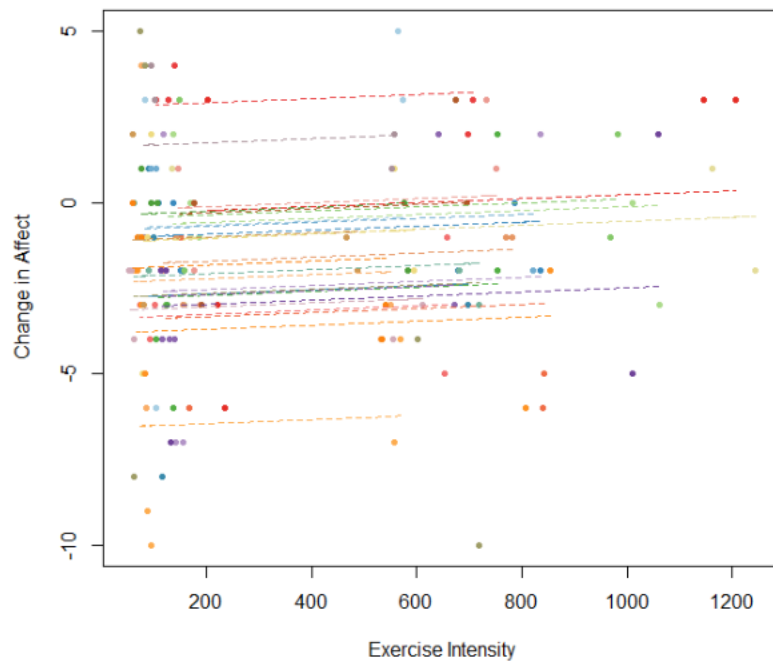
Supplementary Figure 4 Repeated measures correlation between total work done and remembered exercise enjoyment ($r^2= 0.05$, $p=0.01$). Data are presented as individual points for each trial with a correlation trendline for each subject.



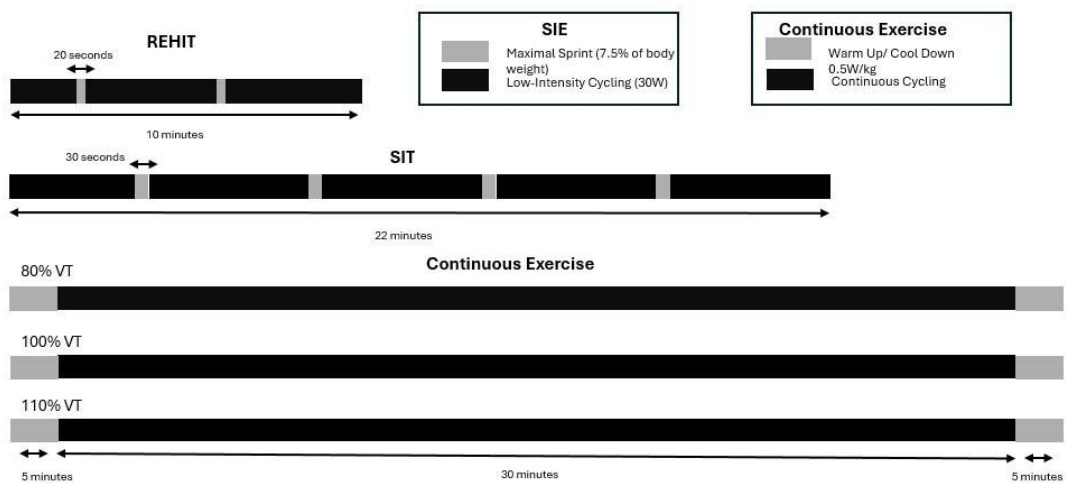
Supplementary Figure 5 Repeated measures correlation between remembered exercise enjoyment and peak exercise intensity (No correlation). Data are presented as individual points for each trial with a correlation trendline for each subject.



Supplementary Figure 6 Repeated measures correlation between the greatest change in AV and total work done ($r^2 = 0.06$; $p = 0.006$). Data are presented as individual points for each trial with a correlation trendline for each subject.



Supplementary Figure 7 Repeated measures correlation between the greatest change in AV and exercise intensity (no correlation). Data are presented as individual points for each trial with a correlation trendline for each subject.



Supplementary Figure 8. A diagram of the 5 exercise protocols used within this study, including durations of each section of each protocol.

Chapter 4: Psychological traits as potential predictors of AV change

4.1: Introduction

Regular PA is important in maintaining good cardiovascular health (Blair and Morris, 2009; Pedersen and Saltin, 2015; Booth et al., 2017; Warburton and Bredin, 2017; Malm et al., 2019) and reducing the risk of non-communicable diseases (Booth et al., 2012; Gillett et al., 2012; Booth et al., 2017). A perceived lack of time is a commonly attributed barrier for PA levels within the adult population (Troost et al., 2002; Nomaguchi and Bianchi, 2004; Korkiakangas et al., 2009; Louw, Van Biljon, and Mugandani, 2012; Baillot et al., 2021; Ilić et al., 2024). To find alternative interventions to address this issue, researchers have studied exercise protocols that provide similar health benefits to MICE but with a reduced time commitment (Burgomaster et al., 2005; Gibala et al., 2006). HIIE and SIE have been found to elicit similar, if not greater, adaptations compared to MICE (Burgomaster et al., 2005; Gibala et al., 2006; Little et al., 2011). However, the total time commitment of these protocols (~90 min a week for SIE and ~66 min a week for HIIE) does not give a meaningful advantage over the currently recommended 75 min vigorous intensity exercise per week. There is also dispute over how applicable SIE and HIIE protocols are for the general population. Due to the vigorous intensity of the exercise bouts, HIIE and SIE are suggested to cause inactive individuals discomfort and result in negative affective responses, in comparison to MICE (Hardcastle et al., 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2020; Ekkekakis et al., 2024). Decreases in AV (feelings of pleasure (positive affect), or displeasure (negative affect)) during exercise correlate with reduced exercise enjoyment (**Chapter 3**), while exercise enjoyment is proposed to be linked to exercise adherence (Williams, 2008; Rhodes and Kates, 2015; Jekauc, 2015). While these findings put doubt on the applicability of HIIE and SIE for the general inactive population, more recent studies show that decreases in core AV during HIIE and SIE are attenuated during protocols with fewer and/or shorter sprints (Martinez et al., 2015; Frazao

et al., 2016; Follador et al., 2018; Niven et al., 2018; Metcalfe et al., 2022), with increases in RPE also attenuated during fewer/shorter exercise bouts (Diniz et al., 2014; Haddad et al., 2014; Kilpatrick et al., 2015; Martinez et al., 2015; Fusco et al., 2020).

REHIT (Metcalfe et al., 2012) was developed as a ‘more applicable’ version of the traditional SIE protocol (Burgomaster et al., 2005) with a total time commitment of 20 min a week that has been shown to elicit similar cardiometabolic adaptations to the traditional SIE protocol (Metcalfe et al., 2012; Metcalfe et al., 2016; Ruffino et al., 2017; Vollaard et al., 2017; Metcalfe et al., 2018; Nalçakan et al., 2018; Thomas et al., 2020), and is therefore a truly time efficient exercise protocol (Cuddy et al., 2019; Metcalfe et al., 2020). The drop in AV during exercise is no different during REHIT compared to MICE (Songsorn et al., 2020; Hu et al., 2022; **Chapter 3**), or HIIE (Songsorn et al., 2020). Recent studies have proposed that SIE/HIIE may be perceived as at least as enjoyable, if not more so, than MICE (Jung et al., 2014; Heisz et al., 2016; Stork et al., 2017; Thum et al., 2017; Oliveira et al., 2018; Stork et al., 2018; Guilkey et al., 2023; **Chapter 3**).

Although affective responses during REHIT have been shown to not significantly differ from MICE, the interindividual variability within participants’ responses highlighted that REHIT can be experienced as unpleasant by some individuals (Songsorn et al., 2020; **Chapter 3**). REHIT may be viewed as more enjoyable and acceptable by some individuals compared to others and therefore the likelihood of uptake and adherence could vary significantly. This interindividual variability suggests that there are mechanisms responsible for the change in AV during exercise other than the exercise protocol itself, which are important to understand in order to positively influence exercise uptake and long-term adherence. Some physiological parameters, such as [La-]b levels during exercise (Astorino and Vella, 2018) and HRV response to a stimulus (Borchardt et al., 2018) have been hypothesised to impact AV within participants. Psychological traits within participants may also play a role in understanding the interindividual variability in the change in AV during exercise, but no research specifically evaluating this link has been done to date.

A study by Tabor et al (2019) found that the combination of greater interoceptive accuracy (measured by the participant counting heart beats while a HR monitor accurately determined the number of beats) and greater levels of anxiety (as measured by the Anxiety Sensitivity Index-3; ASI-3; Reiss et al., 1986) negatively modified relative MPO during sprint tasks. Sections of the Body Perception Questionnaire (BPQ; Porges, 1993) were also measured during this study and no relationship was found with interoceptive accuracy. However, there was a significant correlation between ASI-3 and BPQ scores, suggesting that those who have increased awareness of their bodily events also have increased fear of the symptoms of exercise FA. Individuals who are fearful of the consequence of an action (e.g. sprint performance) subconsciously avoid this action (e.g. reduced power output). Reduced performance in exercise tasks is linked to decreased enjoyment (Box et al., 2023). Intensity trait characteristics such as preference for and tolerance of exercise have been hypothesised to be a factor in determining the interindividual differences in exercise output during self-selected exercise sessions (Ekkekakis et al., 2008). It is theorised that tailoring the intensity of an exercise bout to an individual's intensity trait characteristics will promote pleasurable exercise experiences, and thus benefit exercise adherence (Teixeira et al., 2023). Sense of agency (SOA) refers to an individual's perception over their control of their own mind and body (Tapal et al., 2017). Individuals who have a greater perceived control over their own actions may be better suited to cope with the physiological stress associated with supramaximal exercise. Those with lower SOA scale scores may feel less in control of this fatigue and could potentially feel worse as a result. The aims for this study are 1) to investigate the variability of affective responses to REHIT within and between individuals and 2) ascertain potential associations between the change in AV with exercise and psychological characteristics. It is hypothesised that a greater ASI-3 score (indicating higher anxiety levels) will correlate with a negative affective response to REHIT.

4.2: Methods

4.2.1: Participants

36 healthy, sedentary participants (**Table 1**) were enlisted from two sites; the University of Stirling and Swansea University (18 participants recruited from each site). The exclusion criteria for participation included: <18 or >40 years of age, previous diagnosis, or current evidence, of any chronic diseases, any reasons against performing strenuous exercise as determined using the PAR-Q (Thomas et al., 1992), classified as highly physically active as determined using the IPAQ (Craig et al., 2003), answering yes to one or more questions of a standard PA readiness questionnaire (PAR-Q), resting HR $\geq$ 100 bpm, or blood pressure greater than 140/90 mm Hg (Jones et al., 2019). Participants all gave informed consent in the form of a written consent sheet, which was approved by the University of Stirling Ethics committee (NICR 4297).

Table 1: Participant Characteristics

	Mean
Age (y)	22.4 $\pm$ 4.4
Height (m)	1.73 $\pm$ 0.09
Weight (kg)	70.8 $\pm$ 17.5
BMI (kg/m²)	23.6 $\pm$ 5.1
Watt max (W)	215.9 $\pm$ 68.1
Absolute VO₂max (L•min⁻¹)	2.6 $\pm$ 0.9
Relative VO₂max (mL•kg⁻¹•min⁻¹)	36.0 $\pm$ 10.9

4.2.2: Study design and experimental procedures

Participants attended the laboratory on five occasions, including baseline testing. During the initial visit, participants completed various psychological questionnaires. The ASI-3 (Reiss et al., 1986; Taylor et al., 2007), is an 18-item questionnaire used to assess concern associated with possible negative consequences of anxiety-related symptoms. The ASI-3 scale is scored in three sub-categories: physical concerns, cognitive concerns, and social concerns each with a scoring range of 0-24. The BPQ (Porges, 1993) is a 46-item questionnaire designed to measure body awareness and autonomic reactivity. The BPQ scale is scored in two sub-categories: body awareness and autonomic symptoms. Body awareness has a scoring range of 26-130 and autonomic symptoms has a scoring range of 20-100. The SOA scale (Tapal et al., 2017) is a 13-item self-report measure of an individual's perception over their control of their own body and mind. The SOA scale is scored in two sub-categories; positive SOA and negative SOA. Positive SOA has a scoring range of 5-35 and negative SOA has a scoring range of 6-42. The PRETIE-Q (Ekkekakis et al., 2005) is a 16-item questionnaire that assesses traits of preference for, and tolerance of, exercise. The PRETIE-Q is scored as two sub-categories; preference for exercise, and tolerance of exercise. Items 1, 2, 3, 4, 8, 9, 12, and 13 are reverse scored. Both sub-categories have a scoring range of 5-40. Following the completion of the questionnaires, $\dot{V}O_2$ max was determined using an incremental cycling test to volitional exhaustion (Excalibur Sport: Lode, Groningen, the Netherlands), with breath-by-breath measurement of oxygen uptake using a calibrated online gas analyser (Quark C-PET; Cosmed, Rome, Italy). The highest 15-breath rolling average of $\dot{V}O_2$ was used to determine $\dot{V}O_2$ max, and was accepted if two or more of the following criteria were achieved: (i) respiratory exchange ratio (RER)>1.10, (ii) HR within 10 beats per min of the age predicted maximum HR (220-age), (iii) volitional exhaustion (failure to maintain >50 rpm), or (iv) a plateau of $\dot{V}O_2$ despite increasing intensity.

Participants were familiarised with the REHIT exercise protocol by completing two sessions on separate occasions at least 48 hours apart. Each session was performed on a mechanically braked cycle ergometer (Ergomedic 894e; Monark, Vansbro, Sweden). The protocol consisted of 10 min of non-resisted cycling

interjected with two maximal sprints against a resistance of 7.5% baseline body mass (**Figure 1**). The first sprint finished at 2 min, with the second sprint completing at 6 min. Participants were asked to increase their pedal frequency to maximum in the 3 s directly before the resistance was applied and were verbally encouraged to maintain maximal velocity for the duration of the sprint. The first familiarisation session contained two 10-s sprints, with the second session consisting of two 15-s sprints.

The third and fourth session were the experimental sessions and involved a REHIT session including two 20-s sprints. The demand and resource questionnaire (Wood et al., 2018) was administered pre-exercise to measure participants' evaluation of situational demands and their personal resources to cope with this demand. RPE was measured using the Borg Scale (Borg, 1982), a scale measured from 6 to 20, where 6 means exercise is perceived as very easy and 20 is perceived as being as difficult as exercise could be. Affect was measured using the FS (Hardy and Rejeski, 1989), an 11-point scale where +5 means you feel very good, and -5 means you feel very bad. FA was measured using the FA Scale (Svebak and Murgatroyd, 1985), a 6-point scale where 6 means you feel very high FA and 1 means you feel very low FA. AV and FA were measured at rest before exercise, and then each minute during the exercise bout. RPE was measured every minute during the exercise bout, but not at rest. The PACES scale (Kendzierski and DeCarlo, 1991) was completed 10-min post exercise to measure participant exercise enjoyment. Power output (W) was measured throughout the experimental session to determine PPO, MPO, end power output (EPO), and Fatigue Index.

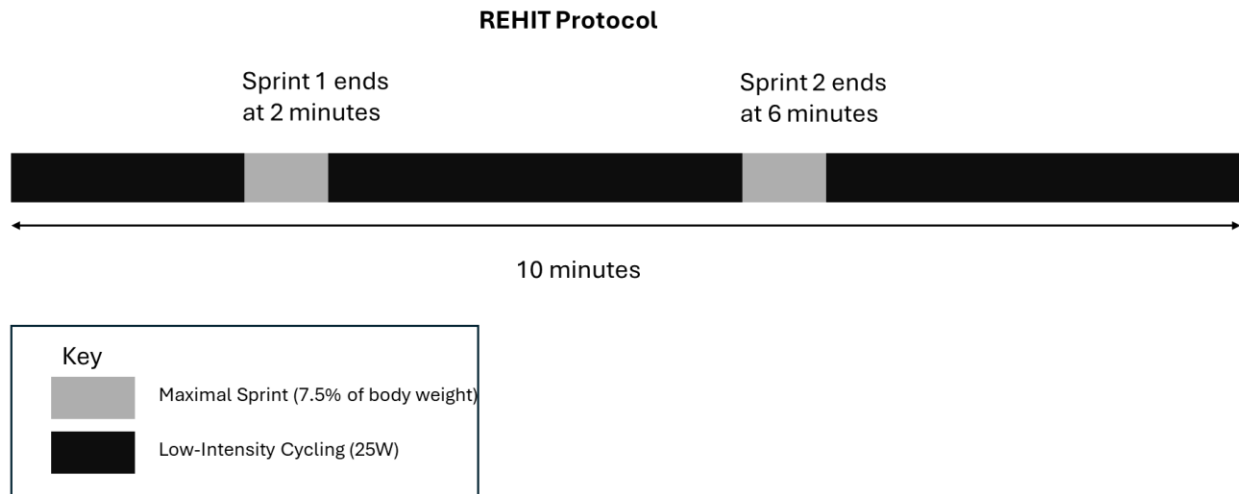


Figure 1. A diagram of the REHIT protocol detailing the timings of the sprints. All in-task experimental measures were taken at 1-minute intervals during the session.

4.2.3: Statistical Analysis

All statistical analysis was performed in Jamovi (version 2.4.11). Pearson's correlation coefficient was used to analyse the consistency in responses for AV change score, FA increase, RPE increase, demand and resource score, and remembered exercise enjoyment between sessions 1 and 2. Paired samples t-tests were used to analyse differences between sessions 1 and 2 for the same variables. If responses were deemed to be consistent between sessions, then the mean value was used for the remainder of the analysis. To identify if any of the variance was shared by any of the study's other parameters, Pearson's correlation coefficient was used to determine correlations within participants, analysing the relationship between mean AV change score and the following variables: FA increase, RPE increase, demand and resource score, remembered exercise enjoyment, BMI, age, Relative $\dot{V}O_2\text{max}$, fatigue index, PPO, MPO, EPO, relative W_{max} , ASI-3 scores (physical, cognitive, social), BPQ scores (body awareness and autonomic symptoms scores, split into supradiaphragmatic and subdiaphragmatic symptoms), PRETIE-Q scores (preference for, and tolerance of, exercise), and SOA scale scores (positive SOA and negative SOA). Data are presented as means $\pm$ SD unless stated otherwise. Statistical significance was accepted at $P < 0.05$.

4.3: Results

4.3.1: Within and between participant variability

Correlations between scores for the first and second session indicated consistent individual responses for AV ($p<0.001$, $r=0.71$), FA ($p<0.001$, $r=0.70$), RPE ($p<0.001$, $r=0.57$), demand and resource score ($p=0.021$, $r=0.38$), and remembered exercise enjoyment ($p<0.001$, $r=0.81$; scatterplots for all correlations in *supplementary material appendices 1-5*). No statistically significant differences were found between sessions for any of these variables. **Figure 2** shows the mean AV change score across both sprints. AV significantly decreased during the sprints compared to the mean baseline values ($p<0.001$). **Figure 3** shows the spread of AV change scores. 75% of the values fell within 1 SD and 97.2% fell within 2 SD points, allowing for normal distribution to be assumed. However, values ranged from -9 FS units to $+2.5$ FS units, with a large SD (mean = -2.78 ± 2.86). 53% of participants (19/36) reported a decrease in AV of greater than 2 (FS units; representing a steep drop in AV), 28% (10/36) reported a decrease in AV up to and including 2 units (a less severe decrease), 8% (3/36) reported a neutral AV response, and 11% (4/36) reported a positive AV response to REHIT.

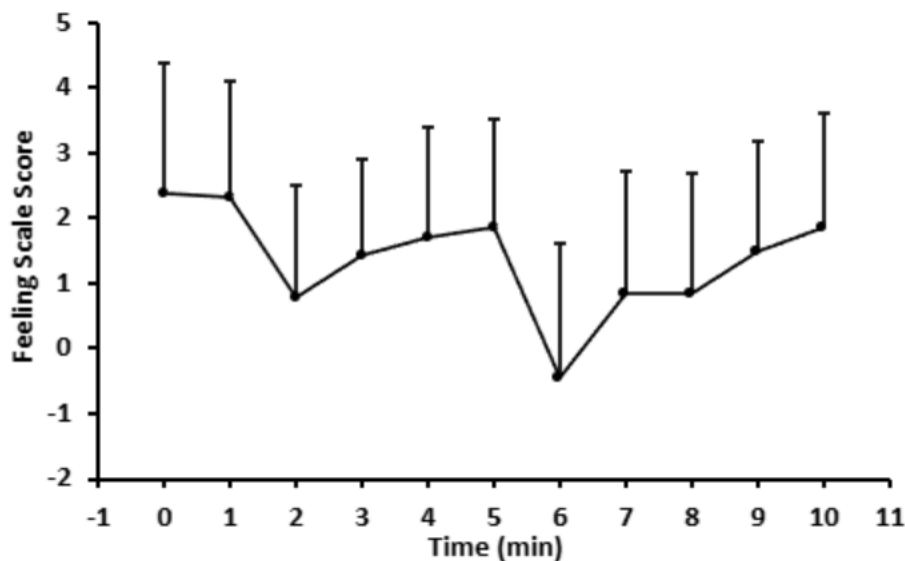


Figure 2. Mean affective responses during REHIT. Data are shown as mean $\pm$ SD

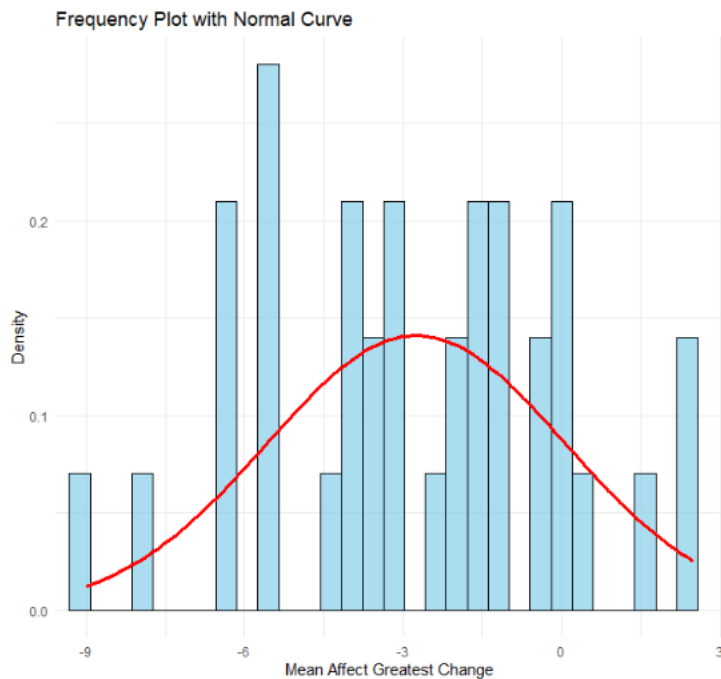


Figure 3. Mean AV change score frequency plot with bell curve.

4.3.2: What correlates with change in AV?

There were no significant correlations between mean AV change score and any of the psychological characteristics assessed (*Appendices 8-16*). There was also no correlation between AV change score and remembered exercise enjoyment or AV change score and demand and resource questionnaire score (*Appendices 6-7*).

Increases in FA negatively correlated with AV change score ($p=0.002$, $r=-0.50$). Similarly, increases in RPE negatively correlated with AV change score ($p=0.025$, $r=-0.37$). However, there was no correlation between the increase in FA and the increase in RPE. PPO, MPO, and EPO. All of the measured power variables showed small, but significant, positive correlations with mean AV change score (PPO, $p=0.023$, $r=0.40$; MPO, $p=0.033$, $r=0.37$; EPO, $p=0.011$, $r=0.44$). Remembered exercise enjoyment also showed a small positive significant correlation with EPO ($p=0.010$, $r=0.44$). Age was also found to positively

correlate with remembered exercise enjoyment ($p=0.001$, $r=0.51$), suggesting that older participants enjoyed the sprints to a greater extent. There was also a significant negative correlation between mean baseline AV and mean AV change score ($p<0.001$, $r=-0.69$).

4.3.3: Other important correlations

There were no correlations between PPO, MPO, EPO and any of the chosen psychological traits. However, there was a significant positive correlation between physical anxiety and supradiaphragmatic symptoms score ($p=0.036$, $r=0.35$), giving minor support to the findings reported by Tabor et al (2019) that body perception plays a key role in interpreting the physiological symptoms of bodily events.

4.4: Discussion

The primary aims for this study were to investigate the within and between participant variability of affective responses to REHIT and ascertain potential associations between the change in AV with exercise and psychological characteristics. Our findings showed consistent affective responses within participants but clear variability in affective responses between participants. Before analysing any traits, we needed to show that the variability of affective responses within each participant was low. Establishing that responses were sufficiently consistent within each individual, with little day-to-day variance without any external modifiers, then allowed us to assess the between subject variability. Multiple studies have found high levels of variance between subjects when looking at affective responses during SIE (Astorino and Vella, 2018; Songsorn et al., 2020; **Chapter 3**). The existence of high between subject variance suggests that there is not a uniform pleasure response to SIE, despite some authors in the field suggesting a homogenous decrease in AV at exercise above certain intensity thresholds, such as the RCP (Ekkekakis et al., 2008; Ekkekakis et al., 2020). We have shown that some participants may find the exercise pleasurable, some will stay neutral,

and there will be varying levels of displeasure felt. This has implications for exercise adherence as it is suggested that pleasure during exercise can predict long-term exercise adherence (Williams, 2008; Rhodes and Kates, 2015). Identifying factors that can explain an individual's AV response to exercise could potentially predict exercise adherence. However, no significant correlations were found between mean AV change score and any of the assessed psychological characteristics. While none of the psychological traits assessed in this study were shown to correlate as predictors of change in AV during REHIT, it must be stated that the sample size for this study may not be suitably powerful enough to draw strong conclusions. As this study was novel, a power calculation was unable to be conducted but it would benefit the field to have a similar study completed with a greater sample size.

We have previously found a direct correlation between decreased AV during exercise and reduced remembered exercise enjoyment levels (**Chapter 3**); however, this current study did not find those same results. Our previous study investigated enjoyment across 5 acute exercise protocols; REHIT, traditional SIT, and three MICE bouts at 80%, 100%, and 110% of the intensity relative to the VT. That previous study also included a mix of exercise and activity levels. This current study only investigated REHIT, and the participants were all classified as low active according to the IPAQ (Craig et al., 2003). The correlation found in the previous study was a repeated measures correlation for all 5 trials for each participant. When analysing the correlation for each trial individually using Pearson's coefficient, no significant correlations were found between the drop in AV of any of the 5 trials and the remembered exercise enjoyment for the same trial. The key finding from the previous study was that the total time spent at a reduced AV correlated with lower remembered exercise enjoyment levels, not how steep the drop in AV was at a singular point. This is consistent with literature as Raedeke (2007) found only positive AV to relate to enjoyment, with negative AV responses not correlating with enjoyment. It is possible to hypothesise that individuals do not remember the lowest feeling of displeasure post exercise, but rather how long they spent in a state of lowered pleasure (from baseline).

The negative correlation between AV change score and FA increase is a novel finding. In our previous study (**Chapter 3**) we found a repeated measures correlation between FA increase and remembered exercise enjoyment, but no correlation between AV change score and FA for any of the individual trials aside from the exercise at an intensity of 80% of the VT ($p=0.015$, $r=-0.45$; these data were not published). In this study we have found no correlation between FA and remembered exercise enjoyment. A potential reasoning for this difference is the robustness of the statistical tests used to produce the results in each chapter. In **Chapter 3** the correlation analysis was conducted using repeated measures correlations (Bakdash and Marusich, 2017) conducted in r-studio, which allowed the data of five differing trials all conducted by the same sample, compared to chapter 4 where a correlation matrix was used to analyse the data (Pearson's correlation coefficient; Sedgwick, 2012).

The increase in RPE also negatively correlated with AV change score, though the correlation was significant but not strong. As individuals perceived the exercise to be more difficult, they felt greater feelings of displeasure, though this could be a reverse correlation where the greater the feelings of displeasure (negative affect), the more difficult the exercise was perceived to be. This is consistent with current literature that states RPE to be a moderator of AV change during exercise (Oliviera et al., 2015; Astorino and Vella., 2018; Farias-Junior et al., 2020). It has been shown that physiological demands during exercise influence RPE change. Peripheral factors and central cardiovascular responses, specifically HR, have been hypothesised to cause perceived exertion to increase (Borg, 1990; Scherr et al., 2013; Lloyd et al., 2016; Levine and Buono, 2019). Alberton et al (2011) found a correlation between increases in RPE and many of the physiological variables that are hypothesised to be symptoms of the increase in FA such as HR, breathing rate, and oxygen uptake. However, no correlation was found between FA and RPE in this study. RPE and FA are both found to correlate with increases in effort during exercise (Presland et al., 2005; Ávila-Gandía et al., 2020) but the relationship between RPE and FA does not appear to have been fully investigated.

All relative power output data showed small positive correlations with AV change score, which could potentially suggest that individuals who feel greater pleasure (or reduced feelings of displeasure) during the sprints perform better, or that performing better during the sprints leads to greater AV levels. This aligns with the finding that those who perceived the sprints as more enjoyable were able to sustain their power output to the end of the sprints to a greater degree compared to those who perceived the task as less enjoyable, or vice versa that performing better leads to greater remembered enjoyment, it is currently unclear which.. The findings from this current study contrast with the findings shown by Tabor et al (2019) that anxiety index was a predictor of relative power output. Tabor found that interoceptive accuracy alone was not a predictor of relative power, but high anxiety sensitivity was, and that the relationship between anxiety sensitivity index and interoceptive accuracy was significant, suggesting a moderating effect. The findings of this current study do not support the link hypothesised by Tabor et al (2019) as no correlation was found between any of the relative power output data and any of the psychological traits assessed, including anxiety sensitivity index. The positive correlation between physical anxiety and supradiaphragmatic symptoms score shows there may be a link between increased anxiety and awareness of bodily events, however this study has found no link between either trait and how one feels during repeated sprints, or their performance during the sprint tasks, which makes the finding less relevant in a SIE context.

The key limitation for this study was the number of psychological traits assessed for the number of participants in the study sample size. As this was a novel study, there were no previous data to perform a power calculation making it difficult to ascertain the true power needed for the study. The findings do not appear to suggest a potential meaningful relationship that was overlooked due to statistical power, but this cannot be categorically ruled out. The complexity of human psychobehavioural traits is difficult to fully analyse and understand using just questionnaires, as self-report measures may not capture unconscious processes, contextual influences, or behavioural variability (Paulhus and Vazire, 2007). A future approach that may benefit this field would be to use a mixed-methods model to investigate each of the traits analysed

in this current study to give a much greater depth of understanding of the traits and how they interact with AV. AV could be measured using more comprehensive methods, such as the PANAS (Watson et al., 1988) and PANAS-X (Watson and Clark, 1994), which allow for a more comprehensive understanding of positive and negative affect, and how these are independent of each other. The sole use of questionnaires also allows for self-reporting bias. It has been shown that self-reporting can be influenced by perceived social acceptance, recall issues, and a misunderstanding of the questionnaire items which can all skew the results of the dataset (Johnson and Fendrich, 2005). This risk of bias could be alleviated through a greater sample size (Cohen, 1992), though some bias will inherently remain. Another key limitation of this study was the limited number of psychological traits assessed. We selected traits that had previous links to exercise performance or were deemed as logical additions. While we can state that anxiety sensitivity index, body perception, sense of agency, and preference for and tolerance of exercise are no predictors of change in AV during exercise, we cannot state that psychological predictors do not exist. At this current moment there are no known links between any other psychological traits and AV during exercise. Another limitation of this study was that we did not assess any non-invasive potential physiological predictors alongside psychological measures, despite knowledge of links between some physiological variables (such as breathing rate and HRV) and the change in AV during exercise. It should also be stated that the findings from this study are lab-based and thus may not translate perfectly to a real-world setting (Brewer, 2000), particularly (in the context of REHIT's potential future applications) a workplace environment. The social implications of workplace peers may interact with the psychobehavioural traits in a way that is not shown within this study.

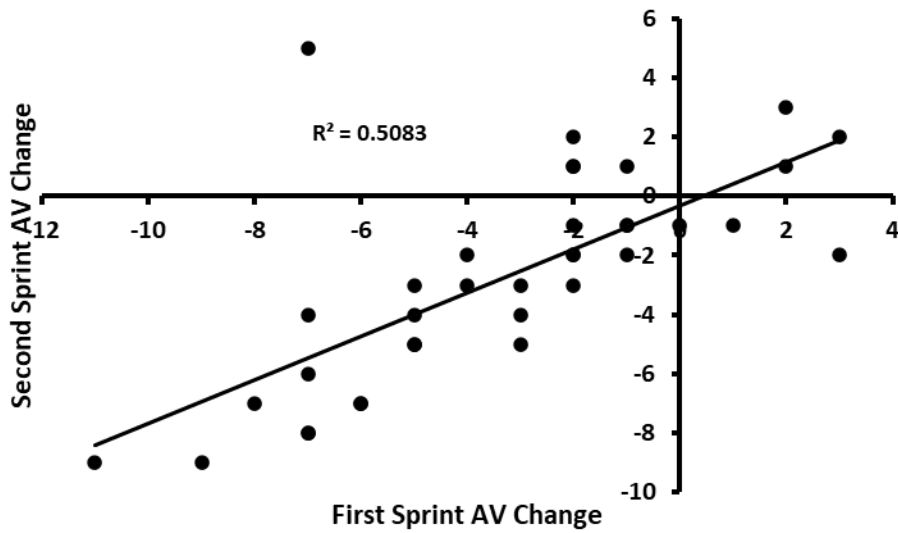
Future research following on from this study should look at potential physiological predictors of AV change during exercise. [La-]b during exercise (Astorino and Vella, 2018) and HRV (Borchardt et al., 2018) have been suggested to predict AV. Astorino and Vella (2018) found that, in studies that assessed AV, RPE, and [La-]b, 62% of the change in AV across multiple trials could be explained through the association of baseline affect, [La-]b, and remembered exercise enjoyment. As reported in this current study, the greater

an individual's baseline AV the greater their decrease in AV during exercise. We have also previously shown a correlation between AV change score and exercise enjoyment using repeated measures correlations (**Chapter 3**). [La-]b is the only factor in the association identified by Astorino and Vella (2018) that has not been investigated in its own study. The lack of any correlations between psychological predictors and AV change in this study leaves the potential for a physiological predictor of AV change during exercise. HRV is another physiological factor that could potentially influence AV change during exercise. Borchardt et al (2018) found that negative AV, due to watching either 'sad' or 'neutral' movies, was associated with reduced HRV and mood. While this link was not created through exercise, the hypothesis that reduced HRV, the reduced ability of the heart to deal with external stressors, impacts AV could be easily applied to an exercise context. Given the findings of this current study that increases in FA are linked to decreases in AV change, breathing rate and HR during exercise, alongside baseline HRV (all physiological responses to the increase in FA), could all be identifiable physiological predictors of AV change during exercise.

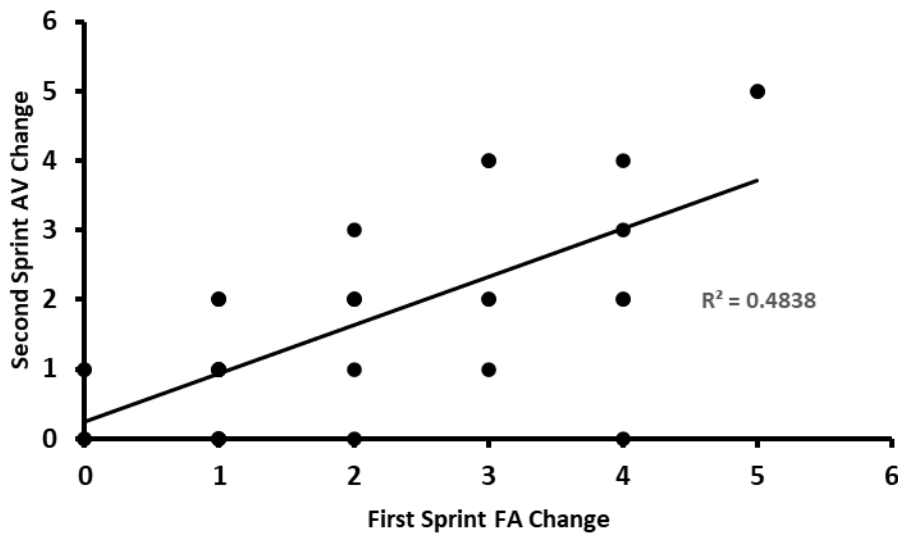
A further possible predictor of AV change during exercise is the deoxygenation of the prefrontal cortex (PFC) during exercise. It is hypothesised that the deoxygenation of the PFC during exercise causes feelings of displeasure as cognitive function is impaired due to blood flow to the PFC being restricted (Ekkekakis, 2009; Ekkekakis and Brand, 2019). A more recent meta-analysis found that PFC oxygenation increases up to the RCP and oxygenation decreases beyond this threshold (De Wachter et al., 2021). This hypothesis was focused on the physiological demand of MICE (typically 30 min bouts), and it is unknown if the very short duration of the REHIT sprints allows for deoxygenation to occur to the same extent as the gradual deoxygenation associated with MICE, despite the supramaximal intensities. A primary study would have to first investigate the relationship between repeated sprints and the deoxygenation of the PFC, and if this link is established, then a study could be conducted investigating the deoxygenation of the PFC using function near-infrared spectroscopy technology to assess the relationship between AV change during exercise and the physiological function of the PFC.

There are not currently any known links between psychological variables and AV outside of the variables tested in this study. It is recommended that anxiety sensitivity, sense of agency, preference for and tolerance of exercise, and body perception be tested for individually to assess each variable in a more statistically robust manner. In future, it is likely that links between other currently obscure psychological variables and performance/affect during exercise will appear, and these should be investigated if/when applicable. Another finding from this study was the small, but significant, link between power output and AV change score. research should investigate if AV change score and remembered exercise enjoyment correlate with improved performance adaptations during repeated sprints. Jaafar et al (2015) found that individuals shown positive valence associated images sustained a greater MPO during repeated 5-s cycle sprints than those shown negative valence images. This effect was only apparent in the first 2 sprints and had no meaningful effect in sprints 3-5. Participants who feel better during repeated sprints are shown to sustain maximal effort to a greater extent than individuals who exhibit feelings of displeasure and this may potentially translate to greater physiological adaptations during long-term training studies. To conclude, there is no correlation between AV change score and any of the psychological characteristics assessed in the study. The findings also refute the claims by Tabor et al (2019) that anxiety index is a predictor of MPO during repeated sprint tasks. Future research is recommended to investigate potential physiological predictors of change in AV during exercise.

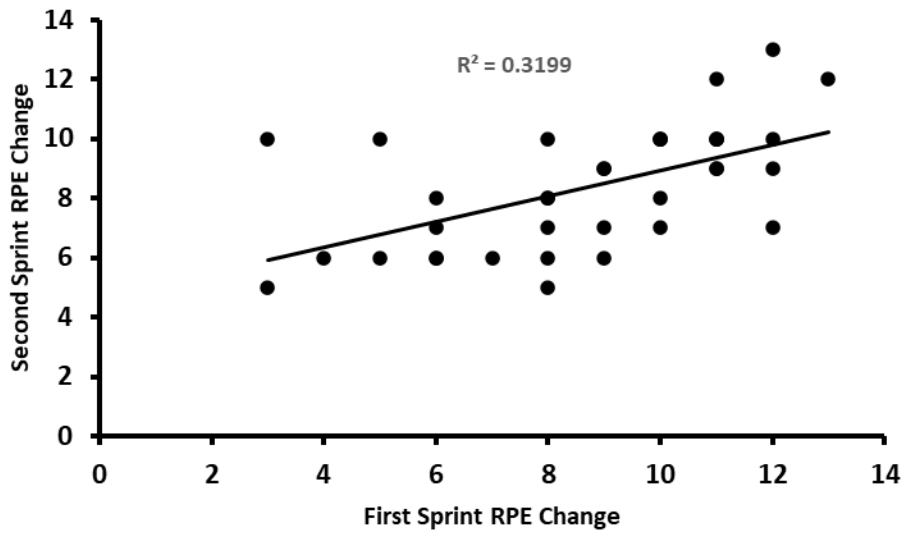
4.5: Supplementary material



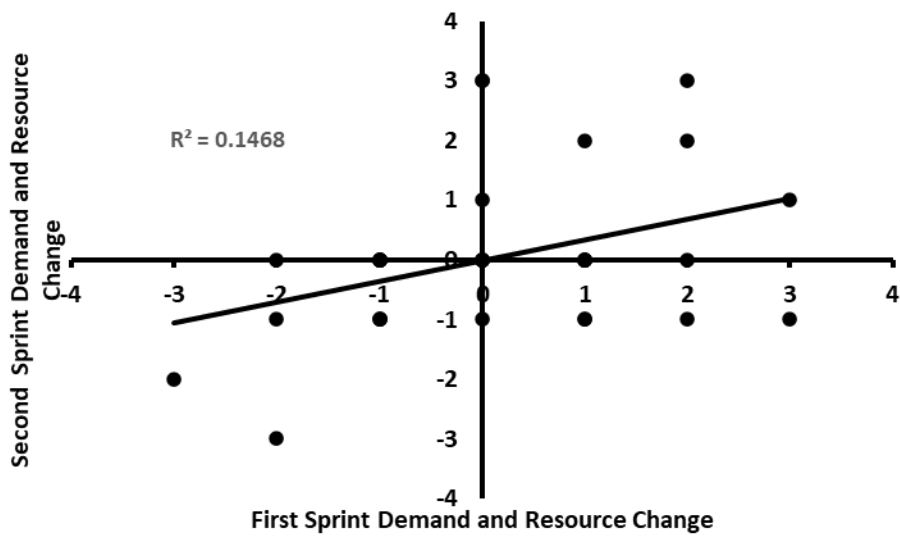
Appendix 1. Scatterplot of the AV change relationship between sessions within individuals.



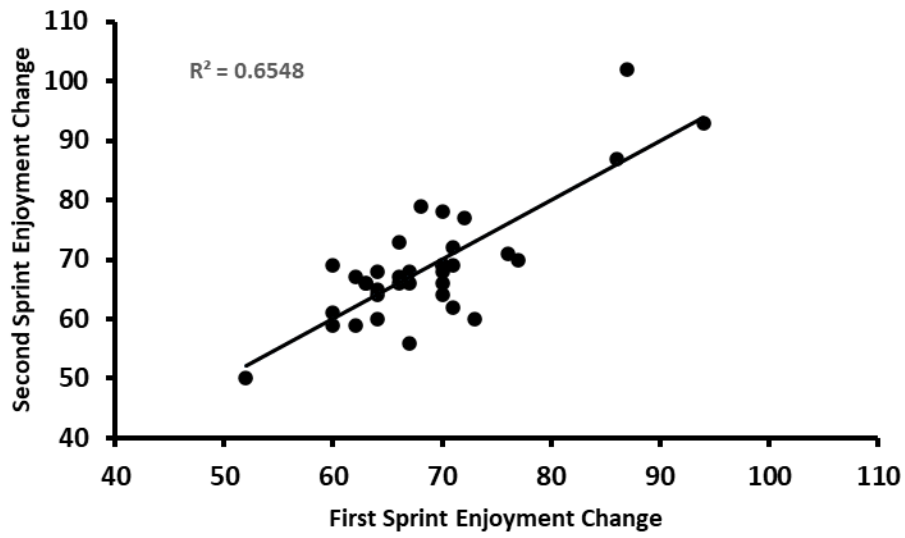
Appendix 2. Scatterplot of the FA increase relationship between sessions within individuals.



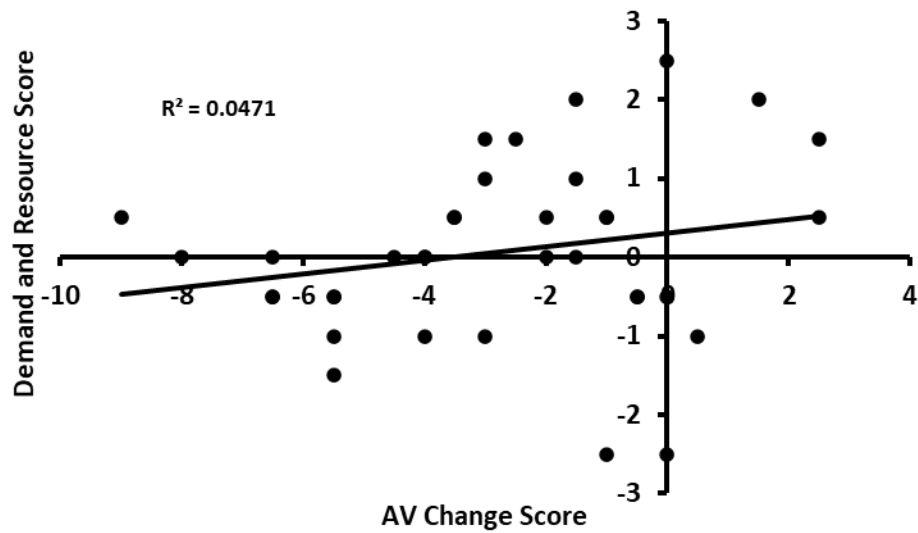
Appendix 3. Scatterplot of the RPE increase relationship between sessions within individuals.



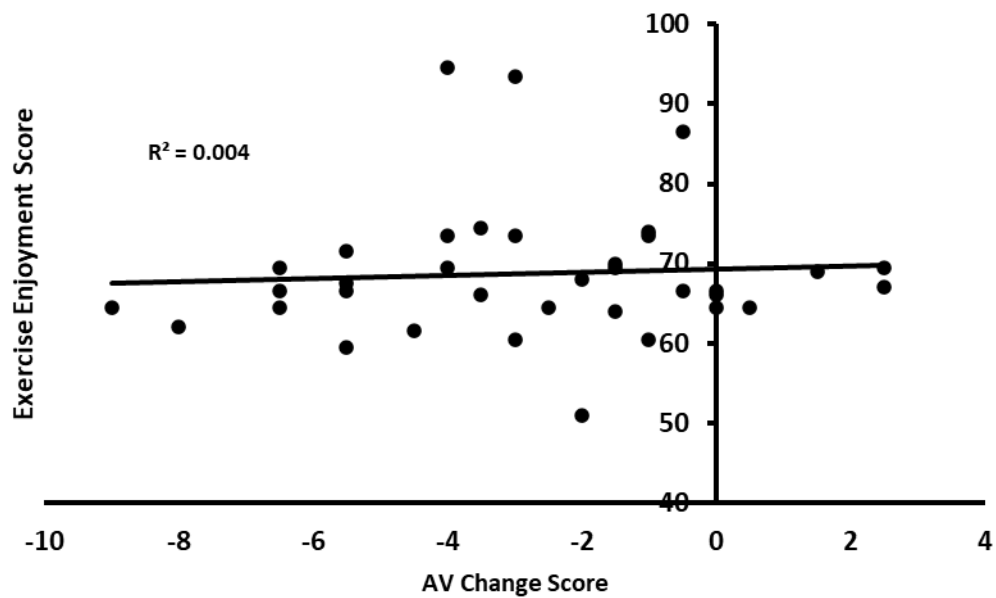
Appendix 4. Scatterplot of the demand and resource relationship between sessions within individuals.



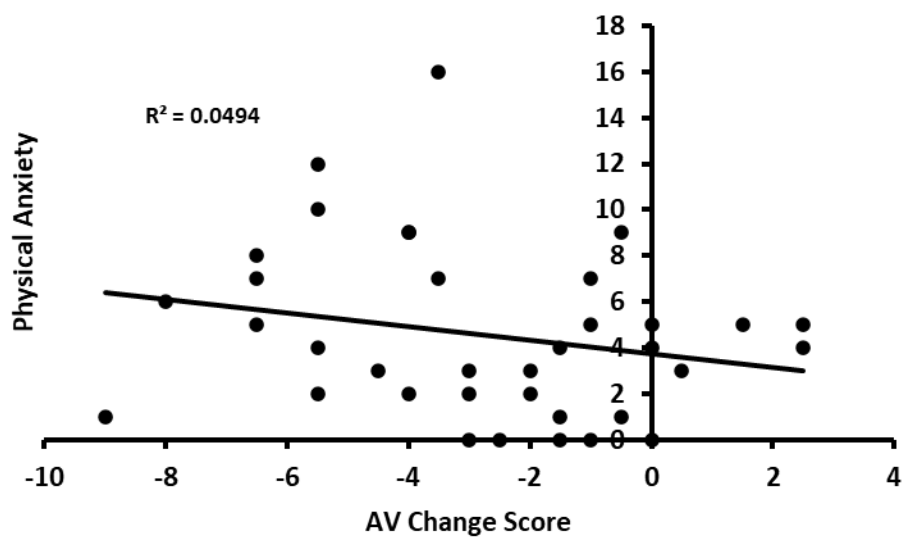
Appendix 5. Scatterplot of the remembered exercise enjoyment relationship between sessions within individuals.



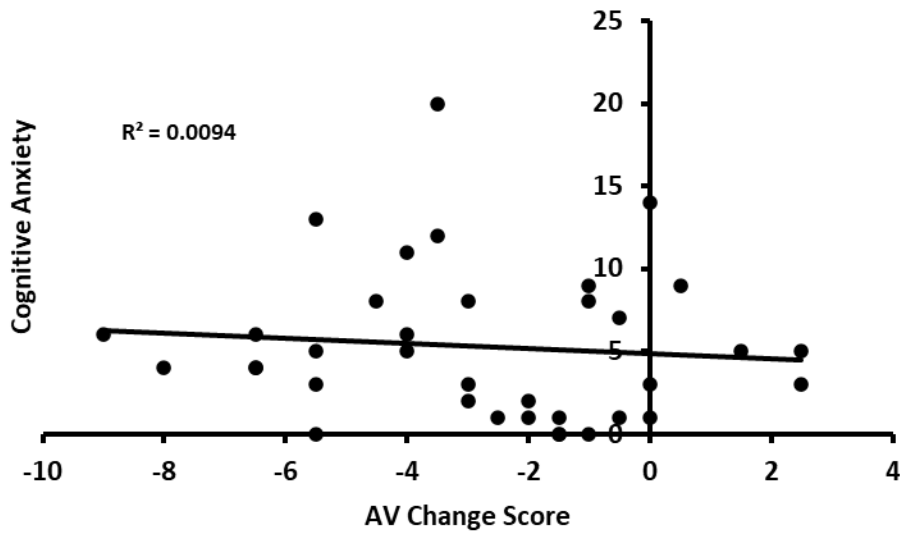
Appendix 6. Scatterplot of the relationship between change in AV during exercise and demand and resource score.



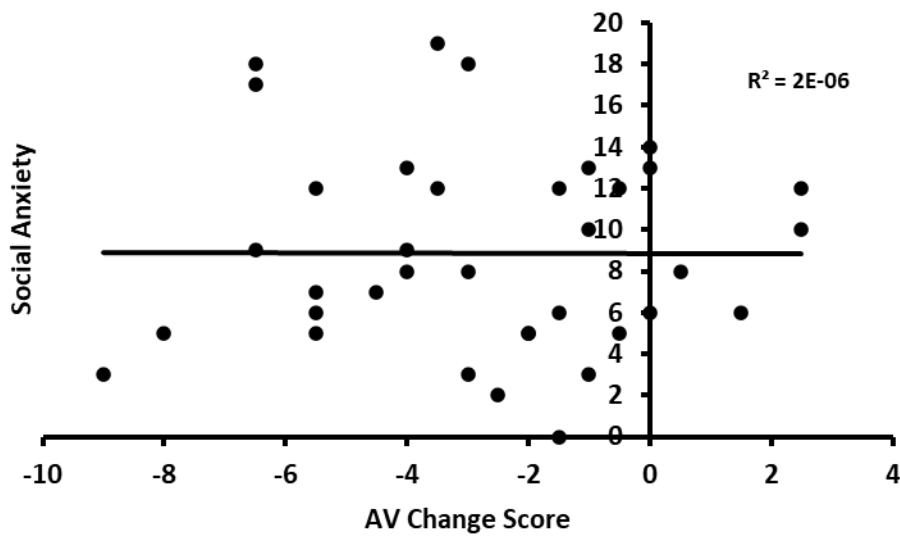
Appendix 7. Scatterplot of the relationship between the change in AV during exercise and remembered exercise enjoyment.



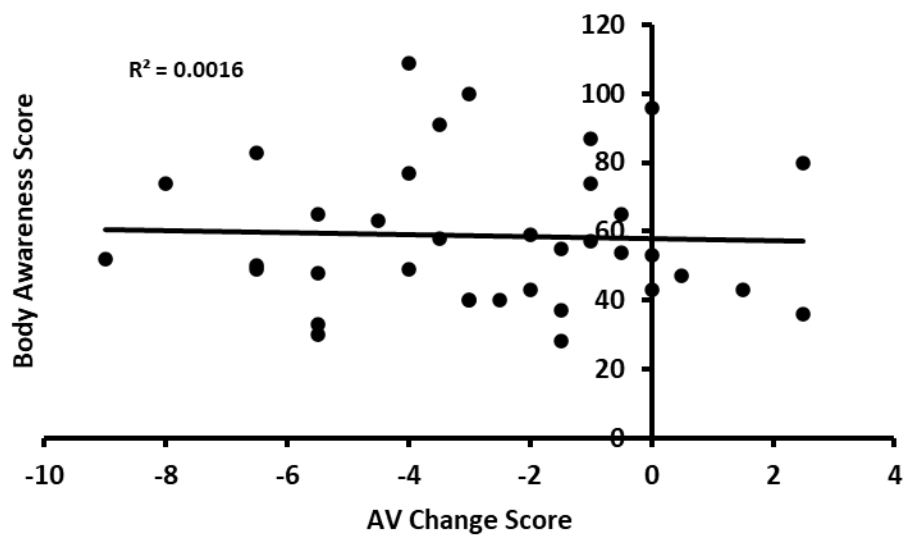
Appendix 8. Scatterplot of the relationship between the change in AV during exercise and physical anxiety score.



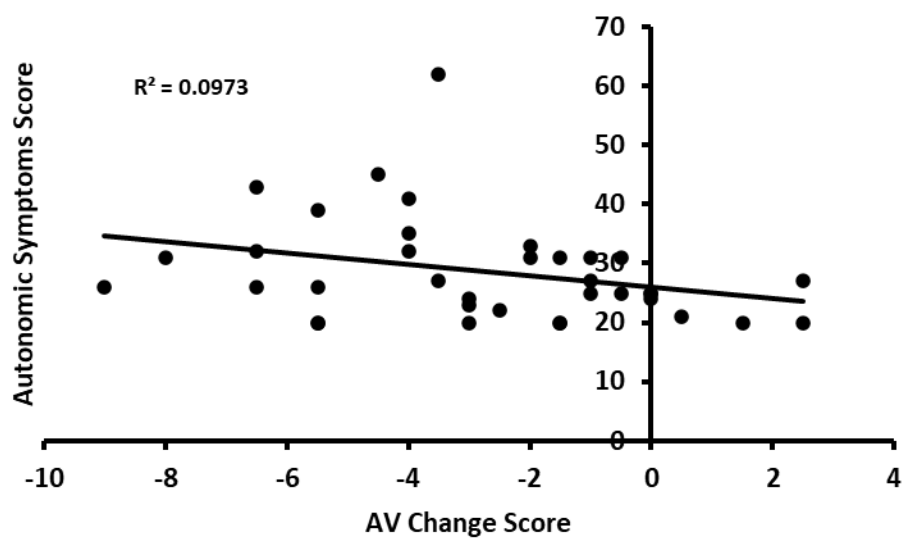
Appendix 9. Scatterplot of the relationship between the change in AV during exercise and cognitive anxiety score.



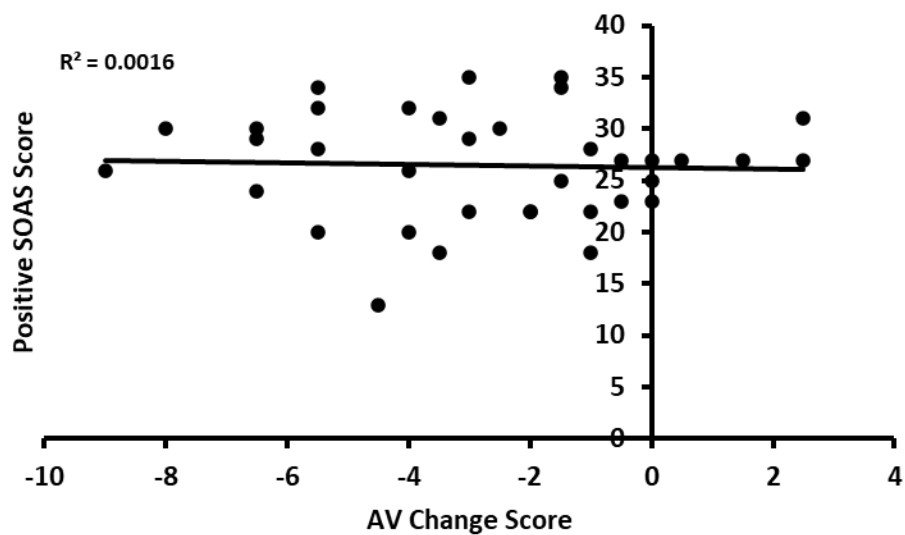
Appendix 10. Scatterplot of the relationship between the change in AV during exercise and social anxiety score.



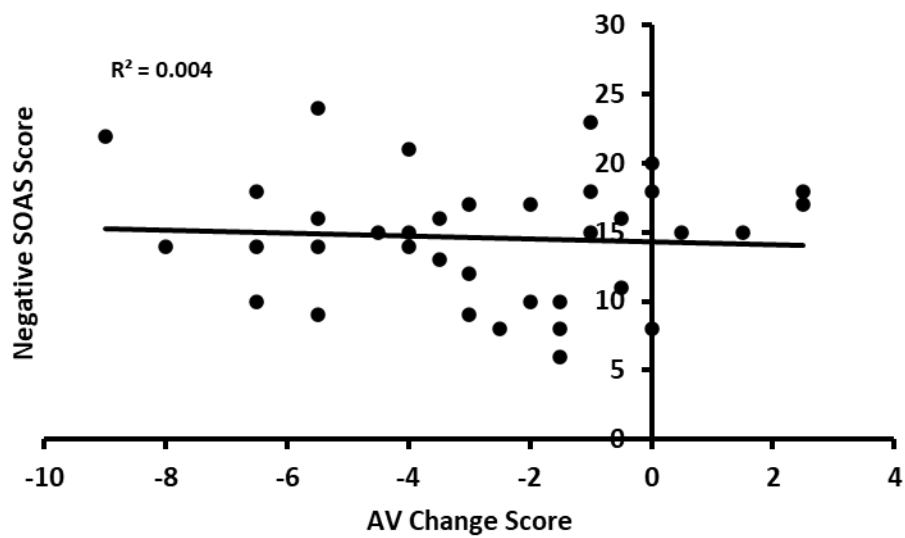
Appendix 11. Scatterplot of the relationship between the change in AV during exercise and body awareness score.



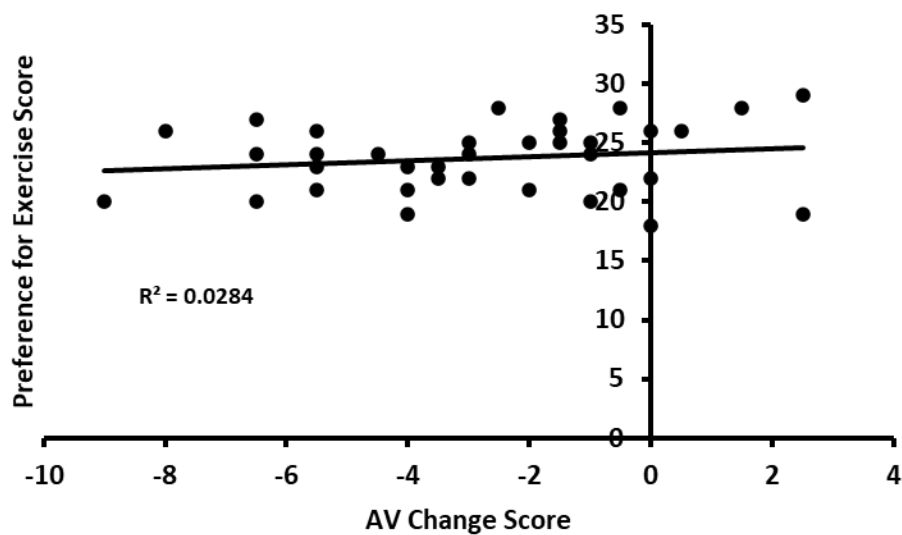
Appendix 12. Scatterplot of the relationship between the change in AV during exercise and autonomic symptoms score.



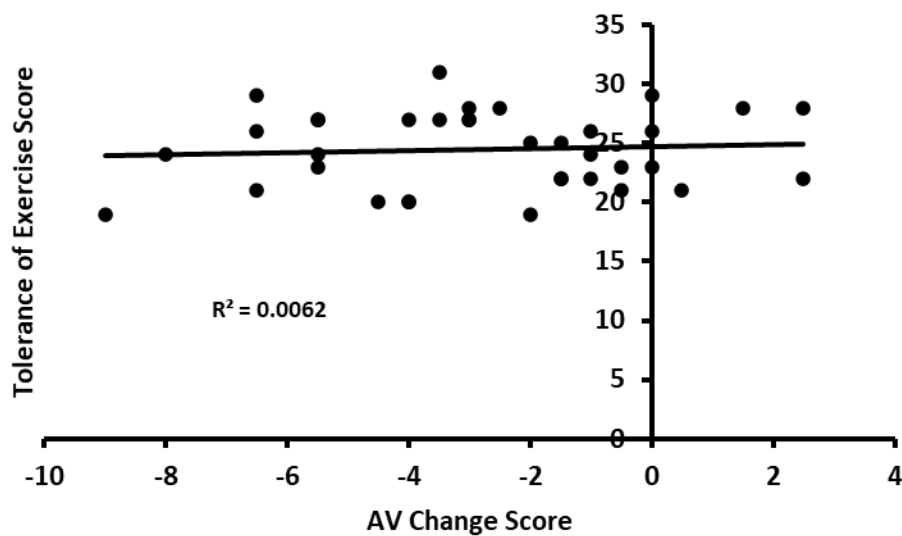
Appendix 13. Scatterplot of the relationship between the change in AV during exercise and positive SOAS score.



Appendix 14. Scatterplot of the relationship between the change in AV during exercise and negative SOAS score.



Appendix 15. Scatterplot of the relationship between the change in AV during exercise and preference for exercise score.



Appendix 16. Scatterplot of the relationship between the change in AV during exercise and tolerance of exercise score.

Chapter 5: General Discussion and Synthesis of Findings

5.1: Topic Overview

Physical activity levels within the general population are a growing and well evidenced issue (Miller et al., 2016; Ruegsegger and Booth, 2018; Strain et al., 2024), with insufficient activity levels reported as the leading cause of 35 chronic conditions (Booth et al., 2012; Gillet et al., 2012). It is estimated that 3-15% of premature morbidity globally is attributed to insufficient activity levels (Lee et al., 2012; Rezende et al., 2019; Strain et al., 2020; Katzmarzyk et al., 2022), indicating a clear need for identification of what potential factors moderate the uptake of and adherence to exercise. One proposed pathway for the determination of the uptake of and adherence to exercise involves the link between decreases in AV during exercise and reduced remembered exercise enjoyment (Raedeke, 2007). Lower remembered exercise enjoyment has been linked with reduced uptake of and adherence to exercise (Jekauc, 2015). Therefore, identifying what factors elicit changes in AV during exercise is key to being able to moderate AV responses during exercise in order to enhance remembered exercise enjoyment and promote the uptake of, and adherence to, exercise.

The intensity of an exercise bout has been proposed as the key determinant for increases or decreases in feelings of pleasure during exercise (Ekkekakis, 2009; Ekkekakis et al., 2020), through the DMM. The DMM states that exercise at intensities up to the VT (moderate domain) will elicit homogenous increases in pleasure, exercise between the VT and the RCP (heavy domain) will elicit a heterogenous response, and exercise at intensities above the RCP (severe domain) will elicit a homogenous decrease in pleasure.

There appear to be shortcomings reported within the DMM and the seminal study (Ekkekakis et al., 2008). Firstly, the protocol used by Ekkekakis et al (2008) consisted of MICE durations lasting only 15 minutes. A checklist published by Ekkekakis and his team (Ekkekakis et al., 2023a; Ekkekakis et al., 2023b) suggests that MICE bouts should last between 30 and 45 minutes so as not to induce bias in AV data, and to reflect the current PA guidelines (Bull et al., 2020). It has been stated by Ekkekakis et al (2023) that, when

comparing MICE with HIIE/SIE, some studies have used MICE protocols with durations that are too long (as the PA recommendations are 30 min). Multiple MICE protocols have reported a gradual downward slope for AV responses (Decker and Ekkekakis, 2017; Songsorn et al., 2020), and therefore the 15 min intervention may be too short to accurately show the AV response. Secondly, Ekkekakis et al (2008)'s intervention involved participants whose VO_{2max} scores suggest that they were trained individuals (female, $n=14$, $VO_{2max} = 47.71 \pm 7.61$ ml/kg/min⁻¹; male, $n=16$, $VO_{2max} = 56.59 \pm 7.27$ ml/kg/min⁻¹). The aerobic capacity of the participants used means that the data may not be applicable to sedentary and inactive populations. Thirdly, the AV responses to exercise at an intensity of 80% of the VT did not demonstrate a homogenous increase in pleasure, as predicted by the DMM. There was great variability reported between participants as only 7% of the participants reported an increase in their AV from baseline, whereas 50% reported no change, and 43% reported a decrease in AV (Ekkekakis et al., 2008).

Contrasting to the hypothesis of the DMM, more recent meta-analyses have shown that enjoyment levels felt during HIIE are not lower than with MICE (Stork et al., 2017; Oliveira et al., 2018; Niven et al., 2021), despite intensities well above the initial point of the severe domain stated by the DMM. The DMM focuses on bouts of continuous exercise, where exercising at severe intensities for the recommended durations would typically induce a greater mean negative AV response (Oliveira et al., 2013; Alicea et al., 2021). The severe domain begins immediately after the RCP which has been found to be 87-88% of VO_{2max} in trained runners and 85-85% of VO_{2max} in trained cyclists (Wiecha et al., 2023). This is considerably greater than the estimated range of the VT of ~50-60% of VO_{2max} . It seems likely, given the data (Stork et al., 2017; Oliveira et al., 2018; Niven et al., 2021), that reducing the duration of these exercise bouts, that are within the severe domain, could attenuate the typically negative AV response. There is diversity within HIIE and SIE protocols from the duration of each repeated sprint to the number of repeated sprints (Gibala et al., 2006; Little et al., 2011; Metcalfe et al., 2012; Haines et al., 2020; Mandic et al., 2023). Metcalfe et al (2022) found that protocols with sprints of a shorter duration and protocols featuring fewer repeated sprints may attenuate the decrease in AV. The findings from the meta-analyses conducted by Stork et al (2017),

Oliveira et al (2018), and Niven et al (2021) could suggest that the link between the more pronounced drop in AV during HIIE and remembered exercise enjoyment may not be as strong as the DMM hypothesises and that the change in AV during exercise may centre around a relationship between exercise intensity and exercise duration, rather than focusing on just one factor.

However, interventions of varying durations and intensities have reported variance in AV responses between participants, despite participants being subjected to the same conditions (Ekkekakis et al., 2008; Songsorn et al., 2020). Songsorn et al (2020) found significant variability in the change in AV (-2.7 ± 3.0) in healthy but inactive participants performing the REHIT protocol. Exercise intensity and duration may influence the mean AV response of a population, but there appear to be further factors that moderate individual responses to exercise. It is therefore important that this variability is confirmed in a focused study, and potential factors that may influence AV responses are studied.

Thus, the overall aim of this thesis was to elucidate what affects the change in AV during different types of exercise and how this is linked to exercise enjoyment levels. Following a comprehensive review of the current literature and introducing the topic in **Chapter 1**, the project focussed on the following key objectives:

1. To meta-analyse all available relevant literature to identify whether the hypothesis of the DMM that exercise below the VT elicits a homogenous improvement in AV, exercise at the VT elicits a heterogeneous response, and exercise above the VT elicits a homogenous decrease in AV, can be confirmed (**Chapter 2**).
2. To elucidate whether exercise enjoyment and changes in AV during exercise depend solely on exercise intensity or on exercise duration as well, by comparing exercise bouts of different intensities and durations (**Chapter 3**).

3. To investigate the variability of AV responses to REHIT within and between individuals (**Chapter 4**).
4. To ascertain potential associations between the change in AV with exercise and psychological characteristics (**Chapter 4**).

The findings of each study have been discussed in detail within the preceding chapters, and the combination of their contribution to advancing the knowledge within this field of research is discussed within this final chapter.

5.2: Chapter 2

The aim of this **Chapter 2** was to meta-analyse the available literature to identify whether the hypothesis of the DMM that exercise below the VT elicits a homogenous improvement in AV, exercise at the VT elicits a heterogeneous response, and exercise above the VT elicits a homogenous decrease in AV, can be confirmed.

Non-linear Bayesian meta-regression of 27 trials from 14 studies found no credible effect of any moderator on the change in AV during exercise. The estimated effect of exercise intensity relative to the VT was 1.05 (95% HDI: -0.34-2.41). At intensities above 100% of the VT, AV decreased in all 7 trials, at an intensity of 100% of the VT, AV decreased in 8 out of 9 trials, and at intensities below 100% of the VT 7 out of 11 trials reported decreases in AV. These findings reject the hypothesis of the DMM (Ekkekakis, 2020) that exercise conducted at an intensity below 100% of the VT will elicit a homogenous increase in pleasure (a positive AV response). Continuous exercise set at intensities below 100% of the VT is theorised to make people feel more pleasure (Ekkekakis et al., 2020), and so the use of other alternative protocols for

promoting activity levels within the general population has been discouraged, particularly higher intensity protocols such as SIE and HIIIE that are suggested to be too strenuous and will make people feel worse while doing them (Hardcastle et al., 2014; Biddle and Batterham, 2015; Ekkekakis et al., 2020).

However, the findings of our meta-analysis show that MICE at intensities below 100% of the VT does not result in consistent positive responses to AV and thus may not hold a discernible advantage over other potential exercise interventions, despite higher-intensity protocols typically leading to reduced AV responses. It appears that all exercise that improves aerobic fitness tends to decrease AV in the general population, but the improvements to aerobic fitness are important enough that exercise must still be encouraged. Therefore, it is imperative to establish which types of exercise protocols are associated with acceptable affective responses rather than homogenous positive responses and note that various exercise types may be suitable for this. The decrease in AV during exercise can be kept manageable for inactive and sedentary individuals, as has been shown with REHIT (Songsorn et al., 2020) and MICE at intensities below 100% of the VT (Ekkekakis et al., 2008), but other factors that may provide an advantage to the general population need to be assessed.

There is still a need for research attempting to identify exercise routines that are physiologically effective and that are perceived as pleasurable by all individuals. However, there is now also scope for research investigating exercise routines that are physiologically effective and associated with a manageable decrease in AV. To achieve this aim, a better understanding of the factors that moderate AV responses to exercise is required. Thus, **Chapter 3** aimed to elucidate whether exercise enjoyment and changes in AV during exercise depend solely on exercise intensity or on exercise duration as well.

5.3: Chapter 3

Four key insights were revealed from our results. Firstly, our data can lead to the conclusion that exercise intensity alone does not determine AV change during exercise. This is due to the decrease in AV during

REHIT (a supramaximal intensity protocol) not significantly differing from the decrease in AV during exercise at an intensity of 80% or 100% of the VT, despite the intensity of REHIT being significantly greater (7.7-fold and 6.4-fold respectively). REHIT was also shown to elicit a significantly smaller decrease in AV when compared to exercise at an intensity of 110% of the VT, despite the 5.9-fold greater intensity.

Secondly, the findings demonstrated an intensity x duration interaction on AV change during exercise. We showed that each of the three MICE trials elicited a gradual progressive decrease over time, and that, despite similar PPO and MPO, SIE was associated with a significantly greater decrease in AV when compared to REHIT. This aligns with Metcalfe et al (2022)'s findings that the duration of each sprint and the number of repeated sprints have a negative effect on AV responses. We also showed a significant correlation between total work done ($W \times \text{duration in seconds}$) and the greatest decrease in AV during exercise, without a significant correlation between exercise intensity and the greatest decrease in AV during exercise, suggesting that higher intensities are associated with a faster decrease in AV, but this can be attenuated by reducing the duration of each exercise.

Thirdly, the results of this study dispute the hypothesis of the DMM (Ekkekakis, 2020) that exercise at intensities below 100% of the VT elicit a homogenous increase in AV (Ekkekakis et al., 2008). These findings align with the results of **Chapter 2**. While exercising at an intensity of 80% of the VT, AV decreased in 51% of participants (15 out of 29 participants), remained neutral in 14% (4), and increased in 34% (10). These findings indicate a clear heterogenous response.

Fourthly, we found a significant correlation between AV change during exercise and remembered exercise enjoyment. REHIT was associated with a significantly lower decrease in AV compared to the classic SIE protocol but the change in AV with REHIT was not significantly different from MICE at 80% of VT. Accordingly, remembered exercise enjoyment was not significantly different between REHIT and MICE at 80% of VT, but significantly lower for classic SIT. This suggests that supramaximal interval exercise can be perceived as at least as enjoyable at MICE if the duration and number of sprints are kept low to attenuate the drop in AV. If applying the theory hypothesised by Jekauc (2015) that greater remembered

exercise enjoyment is linked to improved uptake of and adherence to exercise, then REHIT can be suggested as a feasible exercise intervention for inactive populations.

While the mean decrease in AV during REHIT is no greater than that with MICE protocols, there is large variability in greatest change (at any time measurement) from baseline AV responses to all exercise protocols (REHITD SD= 2.62; SIT SD= 3.24; 80% VT SD= 2.66; 100% VT SD= 3.22; 110% VT SD= 3.64). This could mean that any given exercise protocol may elicit different AV responses from different individuals, suggesting that some exercise routines may be more suitable for some individuals than others. These findings also offer scope to investigate the factors that moderate AV responses during exercise. Thus, the aims for **Chapter 4** were 1) to investigate the variability of affective responses to REHIT within and between individuals and 2) ascertain potential associations between the change in AV with exercise and psychological characteristics.

5.4: Chapter 4

Firstly, to assess variability between participants, we had to ensure that there was minimal variability within participants without any external modifiers. If variability within individuals is high, then assessing interindividual variability and attempting to identify moderators of AV change during exercise would not be possible. Our data demonstrate that AV responses are consistent within individuals between 2 REHIT sessions, but a large SD confirmed variance between participants. The high variance between participants again disputes the claims of the DMM (Ekkekakis, 2020) as there is not a homogenous negative AV response to the supramaximal intensity exercise, as 53% of participants reported a decrease in AV of more than 2 FS units, 28% reported a decrease up to 2 units, 8% reported a neutral response, and 11% reported an increase in AV during REHIT. As the responses are consistent within individuals but differ between individuals, it is reasonable to assume that there must be factors that moderate the change in AV during exercise.

No significant correlations were found between AV change score and any of the psychological traits assessed during this study (anxiety sensitivity, body perception, sense of agency, and preference for and tolerance of exercise). This lends allows for a tentative conclusion to be drawn that these psychological traits do not have a meaningful effect on AV change during exercise , with the added caveat that these conclusions are based on a likely underpowered sample size and thus should be retested (either individually or with a greater overall sample size to test the measures collectively) to ensure statistical robustness. Our findings also dispute the findings of Tabor et al (2019) that anxiety sensitivity index is a predictor of MPO during sprint tasks, as no significant correlations were identified between any of the psychological traits and sprint performance measures (MPO, PPO, EPO). There was a small, significant correlation between the increase in FA and AV change score during REHIT. This could potentially lend support to potential physiological factors associated with the increase in FA, such as HR and breathing frequency, being predictors of AV change. HRV has also been suggested to influence FA (Mohammadpoor Faskhodi et al., 2023), potentially suggesting that the change in AV and increase in FA could be predicted by an individual's HRV. Previous research has identified other potential factors. Astorino and Vella (2018) identified [La-]b as a potential predictor of AV change score. However, the model (which included [La-]b, baseline affect, and RPE) was reported with an R^2 value of 0.60, indicating that 40% of the variance in AV responses cannot be explained by these factors, and thus must be explained through other means. There is a likelihood that physiological factors can help to explain some of the variance, but it is unclear if other factors may be important. It is currently unclear what the mechanisms are behind how any potential physiological factors moderate AV change during exercise, and why these factors differ between individuals. The influence of psychological variables on AV change cannot be ignored either. There are a multitude of psychological and psycho-social traits that were not assessed within this study that may have an influence on AV change. Some have been hypothesised such as perception of body fat (Ekkekakis and Lind, 2006), one's anatomical autonomy (Rose and Parfitt, 2012), and one's age and gender (Pavey et al., 2012), but there are many more that do not have any links to AV as of yet, but that does not mean psychological factors can be categorically dismissed. If it is possible to attenuate the effect of these factors, particularly in individuals who report large

negative AV responses, it may be possible to increase exercise enjoyment levels in those participants which can then, in turn, increase exercise participation rates globally, which is the overarching aim of this thesis project.

The findings of this thesis make valuable contributions to the field of PI and public health, specifically factors influencing exercise adherence and uptake. This was achieved through providing data that counters key criticisms against the use of supramaximal exercise as an alternative exercise intervention for improving general health and wellbeing. The data reported in this thesis demonstrates that most exercise will be unpleasurable for most individuals. However, the drop in AV during exercise can be moderated (lower intensity exercise, or high-intensity exercise of brief durations) to make the decrease in AV manageable for sedentary and inactive populations. Therefore, despite well-established criticisms, research investigating the practical applications of low volume SIE should be continued in order to optimise the chances of getting as many people as possible to gain the health benefits of exercise. This includes establishing what factors moderate the changes in AV with different types of exercise.

5.5: Limitations, Applications, and Future Research Directions

It should be noted that a limitation to the robustness of this thesis are the standardised scales used throughout the research. AV, FA, and RPE measurements during exercise are typically measured using simple scales that are widely used due to their repeatability and their temporal advantages, allowing researchers to analyse effects and changes during a session. These scales are the feeling scale (Hardy and Rejeski, 1989), the felt-arousal scale (Svebak and Murgatroyd, 1985), and the Borg scale (Borg, 1982). While this was necessary for the purposes of this thesis and no better alternative currently exists, it must be mentioned as a limitation that the complexity of AV, FA, and perceived exertion cannot be properly captured with the nuance required to make definitively correct psychological conclusions, particularly AV. Positive and negative AV have been shown to be independent from each other (Watson et al., 1988; Watson and Clark, 1994), but there is

no feasible way of measuring AV, FA, or RPE to such complex depth at multiple time-points within the realm of a physical activity task.

We have shown that the decrease in AV during REHIT is manageable for a sedentary and inactive population. REHIT was reported as preferable to MICE and has been shown to not elicit reduced remembered exercise enjoyment when compared to MICE, with remembered exercise enjoyment linked to exercise adherence (Jekauc, 2015). Therefore, the uptake of and adherence to REHIT needs to be investigated in a longer-term study. Based on the findings of this thesis, the following intervention is recommended: A randomised control trial comparing REHIT to MICE set at an intensity of 80% of the VT should be conducted for a period longer than 12 months to allow for long-term associations to be reported. Participants should be assessed for key health parameters, such as aerobic fitness measured using the VO₂max test, as well as their adherence levels. It is recommended to include the measurement of AV responses to sessions at the start, middle, and end of the intervention which would allow researchers to establish if those with more negative affective responses correlate with those who enjoy exercise less, and if those same individuals are more likely to discontinue participation of the intervention. Using the novel finding from **Chapter 4** that the increase in FA duration exercise negatively correlates with exercise enjoyment, and given that RPE could not be used during that study, FA, RPE, and remembered exercise enjoyment should be assessed at the end of every minute of the REHIT protocol and every three minutes during the MICE protocol, to give both 10 in-task values (only during the experimental sessions at the start, middle, and end of the intervention). This study would require a large sample size in order to account for potential drop out. A conservative 80% power calculation using a moderate effect size of 0.5 (Cohen's d) and a dropout rate of 20% estimates at least 158 participants (79 per trial) are required to fully assess the changes in key physiological health measurements. It is difficult to assess the power required to detect differences in adherence at this moment.

We have also quantified the interindividual variability that exists in the AV response to REHIT. It now needs to be established whether the individuals that report a greater drop in AV during exercise, are also

more likely to drop out of exercise participation. If this can be shown, then future research efforts are required to better understand what factors cause the interindividual variability in affective responses, and whether it is possible to modify these factors to reduce the drop in AV. Three physiological factors have been hypothesised; the PFC (Ekkekakis et al., 2020), HRV (Bordchadt et al., 2018), and [La-]b levels (Astorino and Vella, 2018). The feasibility and direction of these potential factors was discussed in depth in **Chapter 4**. The following research questions are suggested to investigate the interindividual variability in AV responses to exercise:

- Can any other hypothesised psychological and social factors, that were not assessed in this thesis, predict individual AV change? For example, perception of body fat (Ekkekakis and Lind, 2006), one's anatomical autonomy (Rose and Parfitt, 2012), and one's age and gender (Pavey et al., 2012). As previously discussed within this chapter, any future study investigating a diverse range of behavioural health variables would need to be suitably powered in order to robustly conduct the required analyses. Low self-efficacy during exercise has been shown to be more prevalent in females compared to males, especially in adolescents (Pender et al., 2002), as well as in individuals with an above average body fat percentage and 'overweight' or above body mass index (BMI) classification (Brooks et al., 2018). It would be advised to look at each of these factors within differing cultures. This would add depth to the analysis and allow for a more comprehensive view of the individual traits.
- Does the deoxygenation of the pre-frontal cortex correlate with reductions in AV as hypothesised by Ekkekakis et al (2020)? Ekkekakis and team (Ekkekakis, 2009; Ekkekakis et al., 2020) propose that the deoxygenation of the PFC will occur to a greater extent during vigorous intensity exercise than during MICE. Reduced PFC oxygen levels are linked to negative impacts on AV and changes in participants' emotional behaviour (Ladwig et al., 2017; Da Silva et al., 2017). It is possible that the very short duration of the SIE sprints could attenuate the deoxygenation of the PFC during the

sprint itself, with the ‘catch-up’ occurring after the sprint has terminated and the recovery period has commenced.

- Does an individual’s HRV, a typical physiological indicator of one’s ability to deal with stressors, predict AV responses during exercise? Do those with greater HRV have attenuated AV drops? Borchardt et al (2018) linked general AV with HRV, and thus it should be investigated whether this finding is transferable to an exercise setting. This link should be explored alongside other potential predictors due to the tenuous initial link to exercise.
- Can an individual's [La-]b response to exercise predict AV responses during exercise? Similarly to HRV, [La-]b has been hypothesised to influence AV change during exercise (Astorino and Vella, 2018). This review found that a combination of baseline AV, remembered enjoyment, and [La-]b could predict 62% of the variance of AV change score. In **Chapter 2** we found that baseline AV did not have an effect on AV change score, therefore looking at [La-]b may be a strong potential predictor of AV change during exercise.
- How do factors such as sleep, diet, alcohol consumption, and caffeine consumption influence AV responses during exercise? There are no links exclusively between these factors and AV change during exercise. However, all of these factors have been shown to influence multiple facets of health and performance (Shirreffs and Maughan, 1997; Burke et al., 2011; Barnes et al., 2014; Spriet, 2014; Fullagar et al., 2015; Thomas et al., 2016; Watson, 2017; Grgic et al., 2018), which has been hypothesised to influence remembered exercise enjoyment (Box et al., 2023) which **Chapter 3** has shown to link with AV change during exercise. .

The findings from this thesis have very clear implications for future research, and public health in general. The previous chapter has expanded the next steps for research possibilities within the field. Practical implications are less obvious, but just as important. The key takeaway is that there is a need to further understand AV responses to various forms of exercise. The current guidelines (Bull et al., 2020) in future need to be updated in future to reflect exercise protocols that are shown to be feasible from an AV perspective. However, until long-term well-powered studies can be conducted to confirm these findings, the practical applications outside of research from this thesis are limited. Chapter 3 showed that low-volume SIE could be a feasible alternative, and thus REHIT, repeated sprint training, and other potential SIE protocols should continue to be investigated and should be advised to be included in updated public health guidelines.

5.6: Overall conclusions

The overall aim of this thesis was to elucidate what affects the change in AV during different types of exercise and how this is linked to exercise enjoyment levels. The findings present clear evidence that challenges the hypothesis of the DMM (Ekkekakis, 2009), showing that exercise intensities below 100% of the VT do not produce a homogenous increase in positive AV. We have shown that both continuous and interval training produce variability in AV responses, highlighting the importance of individual differences.

These findings have demonstrated that low-volume SIE protocols are not only enjoyed similarly to, but are preferred to, MICE. These results counter the common criticism of SIE protocols that the supramaximal intensity will mean that there will be a homogenous negative AV response to these protocols, supporting further investigation into low-volume SIE protocols as viable long-term exercise interventions.

Our data also showed inter-individual variability to REHIT, but that the psychological traits assessed in this thesis do not explain this variability. This indicates that other factors (potentially physiological, environmental, or contextual) may help explain the heterogenous AV response to exercise, offering rich directions for future research.

This thesis has advanced the knowledge of our understanding of the relationship between exercise intensity, AV responses to exercise, and remembered exercise enjoyment. There are research implications for the design of exercise interventions aimed at improving exercise adherence levels and public health. Future research should continue to investigate potential factors that may moderate the change in AV during exercise, and to test the long-term effectiveness of low-volume SIE protocols.

By challenging established models within public health and broadening the scope of the inquiry, this thesis has contributed meaningfully to theoretical and practical knowledge and has opened new opportunities to explore exercise interventions that can help improve public health.

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